Determining The Feasibility Of Using Video Imaging Techniques To Collect Transportation Data

Final Report

RP 112A

Idaho Transportation Department-University of Idaho
Cooperative Transportation Research Program

Prepared by

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September 8, 1993

Mr. John Hamrick
Traffic Survey Unit Manager
Idaho Transportation Department
P.O. Box 7129
Boise, ID 83707-1129

Dear Mr. Hamrick:

I am pleased to transmit to you the final report for the project *Determining The Feasibility of Using Video Imaging Techniques to Collect Transportation Data*. This final report includes a thorough assessment of the capabilities of the Autoscope 2002 system to collect several kinds of transportation data including freeway traffic flow data and vehicle size data. The report covers the results of four separate tests using the Autoscope system: (1) measurement of truck heights, (2) measurement of truck lengths, (3) measurement of truck widths, and (4) measurement of freeway volumes. The report includes all editorial changes that were identified by you and your staff in your review of May, 1993.

Some of the major findings of the research are:

- Estimated truck heights using Autoscope data were within 10 percent of the actual heights for 86 percent of the trucks measured.

- There is a very good correspondence between the actual length of a truck and the number of Autoscope detectors that are simultaneously activated as a truck passes through the video detector grid. Site geometry problems, however, prevented an accurate assessment of the Autoscope truck length measurements.

- There is an excellent correspondence between the actual width of a truck and the width estimated using Autoscope data, with the most errors less than ten percent.

- Correspondence between Autoscope freeway volume counts and volumes measured using software-assisted data entry were within ten percent for most of the sites studied, when optimal detector layouts were selected.

Please note that while these results are very encouraging, the Autoscope technology is not completely error free. Image Sensing Systems, the manufacturer of the Autoscope system, is now developing more advanced detector technology that should address most of the problem areas that we found during this research project. Some of the improvements include reduced errors due to shadows and the possibility of more closely spaced detectors. The new Autoscope 2003 system provides significant improvements and addresses most, if not all, of the problems encountered during this study.

In addition, we have found that there is a significant amount of experience that must be gained in properly applying this technology, particularly in the judicious location of video detectors and in the determination of the proper sensitivity and persistence settings. But once this learning curve has been overcome, the results produced by Autoscope are very good. Clearly this technology has enormous potential for assisting the Idaho Transportation Department in improving the kind and quality of transportation data that can be collected, both for traffic studies and for real time traffic monitoring and control.

As a result of our findings, I would like to make the following recommendations:

- a second phase research project should be developed that builds on the findings of this project. One primary candidate project would be the installation of a site in the Boise area to test the feasibility of using the Autoscope system to control a signalized intersection. There are currently two such on-line projects in the U.S., one in Oakland County, Michigan with nearly 100 intersections under real time Autoscope control, and one in Long Beach, California. A number of other sites are conducting on-line field testing.

- new software should be developed to automate the truck dimension measurement process, building on the manual techniques developed during this project. The University of Idaho is currently developing software to directly calculate turning movements from Autoscope detector data at intersections. The basic matching algorithm used in this program would be similar to one required for the truck dimension measurement process.

- initiation of training of ITD engineers to use the Autoscope system through the new Machine Vision Laboratory now being developed at the University of Idaho.

Again, it has been a pleasure for me to work on this exciting project.

Sincerely yours,

Michael Kyte, P.E.
Associate Professor and Principal Investigator

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the assistance of the Idaho Transportation Department staff during the course of this study, particularly John Hamrick and the staff of the Lewiston Port of Entry, and Randy McGregor and Kishore Kagolanu, University of Idaho research assistants.

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CHAPTER 1. INTRODUCTION

1.1 Background

In September 1990, the University of Idaho and the Idaho Transportation Department, in cooperation with TransNow, initiated a research project to test the feasibility of using video imaging techniques, sometimes called machine vision technology, to collect traffic flow data at unsignalized intersections. As part of this project, the University of Idaho acquired an Autoscope workstation. The results of this earlier project were promising enough to encourage the University of Idaho and the Idaho Transportation Department to undertake a new project to test the feasibility of using the Autoscope system to collect other kinds of transportation data. This current project, *Determining the Feasibility of Using Video Imaging Techniques to Collect Transportation Data*, was initiated in October 1991. The two objectives of this project are:

1. To test the feasibility of using automated vehicle imaging techniques to detect oversize vehicles at ports-of-entry, and

2. To test the feasibility of using automated video imaging techniques to collect traffic data on congested freeways and arterials.

Five tasks were included as part of the project work program.

Task 1. Collect and analyze videotapes of trucks entering the Idaho Transportation Department Port of Entry in North Lewiston. Develop and test alternative video imaging techniques and software processing capabilities to identify oversize vehicles at the Port of Entry. Compare the accuracy of the results with manual or other standard techniques currently in use.

Task 2. Collect and analyze videotapes of traffic operations on I184 in Boise. Develop and test alternative video imaging and software techniques to collect traffic data on the freeway. Compare the accuracy of the results with standard techniques currently in use.

Task 3. Prepare progress report summarizing the results of Tasks 1 and 2.

Task 4. Collect and analyze videotapes of truck operations at other POE sites and traffic operations at other congested freeway and arterial sites. Apply and extend the analytical techniques developed in Tasks 1 and 2 to collect truck overlength and traffic flow data.

Task 5. Prepare final report describing the results of the research completed in Tasks 1, 2, and 4.

This final report describes the results of this research project. Chapter 2 presents a literature survey of video image processing systems. Chapters 3, 4, and 5 present the results of the three kinds of truck dimension measurements that were made using the Autoscope system, height, length, and width. Chapter 6 presents the results of the freeway traffic volume measurement test. Chapter 7 presents a summary of the test results. Chapter 8 presents a summary of the recommendations made from this research. Chapter 9 lists the references that were consulted. Detailed plots of truck profile measurements are given in the appendices.

1.2 Overview

Major technological developments in the past two decades in the field of electronics have greatly affected and revised data collection and incident detection methods in the field of transportation engineering. Traditional methods of data collection are being fast replaced by new innovations in the fields of microelectronics, sensor technology, and image processing systems.

Accurate and easy to use methods for collecting traffic volume counts, turning movement determination, delays, queue length, vehicle classification, signal control, and incident detection have always been in demand by transportation department personnel. This has encouraged research in developing new technologies, utilizing new sophisticated computers and cameras. As the technology is developing, new possibilities are being explored all over the world for application in more sophisticated tasks of data collection and vehicle detection.

The general purpose video camera can be very effectively utilized to obtain real time traffic data by traffic engineers. The basic principle behind all developed technologies for application in transportation engineering consists of using a video camera to record on site data and incorporating image processing technology to process and analyze the video image to determine queue lengths, delay time at intersections, etc. These systems can be installed on a large scale basis covering large segments of urban areas or transportation corridors, and operated and controlled through a central network. These technologies have been and are being tested for changing on site conditions like rain, fog, snow, day/night transition period, congested traffic conditions, and effect of vehicle/fixed shadows.

1.3 Problem Statement

This report analyzes the feasibility of the Autoscope technology, a video image processing system developed by the University of Minnesota and Image Sensing Systems, Inc., for field application by the Idaho Transportation Department to measure truck height, truck length, and truck width, and to measure traffic volumes on freeways.

The Idaho Transportation Department currently uses manual methods for measuring truck height, width, and length, to detect oversize trucks. This method is laborious, time consuming, and requires continuous supervision of passing trucks by transportation department personnel. The high commitment of labor means that it is often not economical.

Conventional loop detectors are used for measuring traffic volumes on freeways in Boise and other parts of the state of Idaho. However, recent studies have shown that for many major U.S. cities, 25 to 30 percent of the loop detectors are not operating or not functioning properly. Another major drawback of these detectors is their inability to extract important traffic parameters. In addition, the loops need to be physically embedded in the pavement surface and this involves digging up of the pavement to install them. Finally another problem associated with this technology is the breaking or bursting of loops under increasing traffic loads.

Both the problems with oversize truck measurement as well as the reliability of traditional loop detector technology now leads to the question of adopting image processing technology for traffic data collection and management. Is it suitable? Is it accurate? These issues will be explored in this report.

CHAPTER 2. LITERATURE SEARCH

2.1 Introduction

Image processing is the analysis of video picture data or information. The video image can be processed by either optical, analog, and digital processing technologies. The history of image processing technology can be traced back to the development of United States space technology in the early 1960's. Originally NASA scientists used analog image processing technology but later discovered the advantages of digital imaging systems. The first concerted effort for applying this technology in the field of transportation was done in 1978 when the Federal Highway Administration (FHWA) contracted with the Jet Propulsion Laboratory (JPL) to investigate the feasibility of using video sensors and image processing for automatic traffic monitoring and to develop a breadboard system. This culminated in the development and testing of a breadboard system, called a Wide Area Detection System (WADS), for vehicle detection and vehicle velocity measurement [5].

Research in developing image processing based technology and its application in traffic data collection is also active in Japan and Europe. The British have developed two systems for traffic data collection: the Traffic Tracker developed by Sense and Vision Electronic Systems Ltd., and the Traffic Analysis System developed by CRS. The Camera and Computer Aided Traffic Sensor (CCATS) system was developed in Belgium by Devlonics Company in collaboration with the Belgian government and the University of Leuven. Other systems in the implementation stage are ATAS, Tulip, Sigru (Spain), and Titan (France).

2.2 Image Processing Technology

An image processing system can be divided into three components based on function. They include the image acquisition, image processing, and image display components.

Image Acquisition is the first step involved in an image processing system. The original image from the video camera is converted into digital format to make it compatible for processing by a computer. There are two alternatives available for a computer to read a video image in a digital format. The real time analog image can be converted into digital format by an image collection device or the image can be directly recorded in digital format. It is better to digitize the image first and then to enter it to the computer for processing. Film scanning systems and video digitizers are the two available methods for digitizing an image. Since video technology is cheap and flexible with respect to transportation and installation, video digitizers are the most suitable technology for highway and transportation data collection.

The conversion of the video image from analog to digital format requires very powerful computers with high processing speeds and large memory. A standard video signal transmits images to a monitor at a rate of 30 frames per second and each frame consists of 525 lines and each line has 512 pixels or picture elements. If each pixel occupies one byte of memory then host computers with a processing speed of 8 megabytes are required to process the video input signals. Mini and micro computers with this amount of processing speed are not yet available, but in transportation field applications these are the type of computers that are most suitable. Alternative methods have evolved to solve this problem. A frame grabber board, which makes the analog to digital conversion at full speed and which stores the digitized data in a digital frame buffer, can be installed. This stored data is transmitted to the host computer for processing at the lower speed for which it is capable. Another method is to reduce the number of pixels to be processed i.e., instead of the complete TV screen image a small region can be defined by the user. This method is known as the *tripwire* method of detection. This method considerably reduces the processing speed requirements for the host computer. This technology is the most suitable for transportation applications.

Image Processing. The next step after the collection of the image in digitized format is to process it to give the desired results. There are two types of image processing technologies. The first one consists of enhancing the image which deals with improving the visual interpretation of the picture and makes it possible for human observers to understand and interpret the image visually. The second, known as quantitative image processing, involves mathematical models to extract information about the image. Quantitative image processing is more suitable for traffic data collection.

Image Display. The last of the steps is the displaying of the processed data. This requires digital to analog conversion and transmission of the signal to a video terminal. The other available display devices are printers, plotters, film recorders, microfilm recorders, and data storage devices.

2.3 Image Processing Systems

Some of the most prominent technologies that have been developed and are in the development stage are discussed in this section. The technologies described in reference [4] are summarized.

ATAS: The Aspex Traffic Analysis System (ATAS) is in its early development stage and some modifications are necessary to make it more efficient and feasible for field implementation. The present status of this equipment indicates that

- it can detect traffic coming only toward the camera i.e., it has directional restrictions,
- it needs a supercomputer to perform the image processing computations, which implies that it might be expensive,
- it has a very easy program for system initialization,

- the system lacks a mechanism for communications with a central location and needs a change in software to download configurations, and
- the system performs well under standard site conditions and shows inadequate results during day/night transition period and night scenes with steep camera angles.

CCATS: The Camera and Computer Aided Traffic Sensor (CCATS) is a fully developed system, manufactured and marketed by Devlonics (Belgium). There are a few problems existing in this system and it needs modifications in software to increase efficiency for field implementation with changing circumstances. The following points reflect the current status of this system:

- it operates well under standard site conditions during day time,
- it operates well under somewhat abnormal conditions like noise, shaky camera, traffic jams, fog, rain, shadows, side and shallow camera locations,
- it is capable of detecting vehicles in three lanes only,
- it is not efficient in detecting vehicles during night or poor lighting conditions,
- the system is not sensitive in detecting vehicles in shadows, and
- it is difficult or laborious to incorporate this system in a large network i.e., the system parameters cannot be changed remotely, for example, the changes in sensitivity of the system needs local connection to each unit's initialization port.

Sigru: This system is manufactured by Eliop (Spain) and is in its development stage. This system has some restrictions with respect to the height of the camera, but since this system is in its development stage, any system deficiencies can be improved by altering its hardware and developing new or modified software. The results or observations from tests conducted at Cal Poly indicate the following points:

- this system gives optimum results when the camera height is 45ft. At lower camera heights, the results indicate overestimation of traffic volumes,
- its application is limited for analyzing traffic in three lanes only,
- it gives inappropriate results in the presence of vehicle shadows,
- it is accurate in detecting speeds of vehicles as compared to count data even in bad site conditions,
- its initialization program is very easy to use and efficient, and
- it gives inaccurate results when the system is installed to analyze traffic data collected from a side view.

TAS: The Traffic Analysis System (TAS) is a fully developed system using tripwire technology to identify moving vehicles. This is a turnkey system equipped with communication facilities for installation in a wide area network. This system is suitable for ideal conditions and its performance efficiency reduces with changing site conditions. The algorithm incorporated for collecting data during the night/day transition phase is very efficient as compared to the other systems. Some of points illustrating the system performance are mentioned below:

- this system is efficient for ideal site conditions and is not suitable for drastically changing site conditions like weather,
- the system requires fine tuning of its parameters and the is often difficult to do for someone unfamiliar with this equipment,
- the power of analysis is limited to three lanes only,
- the system is not flexible for parameter adjustment for each individual lane,
- it requires light traffic conditions during initialization phase, and the results generated during congested traffic conditions deteriorate as compared to light traffic conditions, and
- it is very flexible for field deployment with ability to remotely adjust the system parameters.

Titan: This French system is under development by the Institut National de Recherche sur les Transports el leur Securite (INRETS). This system incorporates blob identification technology to detect moving vehicles. This system is very efficient for detecting vehicles during day time. The following points summarize its strengths and weaknesses:

- the system can analyze traffic in five lanes and its speed measurements are very accurate,
- it has an algorithm that automatically adjusts parameters during day/night transition,
- the performance is poor during night periods, congested traffic conditions, and when heavy stationary shadows are present,
- installation of this system is very difficult for a camera position having a side view of the lane, and
- As this system is still in its developing stages many improvements are feasible for effective field implementation.

Traffic Tracker: This system uses a vehicle tracking method for vehicle identification. This is a system for turning movement detection at intersections. It does not have an algorithm for speed detection of vehicles. This system can be modified to count vehicles on freeways. Some of the characteristics of this system are described below:

- it can monitor traffic in five lanes,
- the initialization of this system is very difficult unless the person is skilled and familiar with the

system,

- there is no provision for installing this system on a wide area network,
- there is a lack of clarity in understanding the effect of parameter setting on performance of the system,
- the system does not adjust itself for changing situations i.e., the parameters are not updated automatically by the system, and
- one of the unique features in this system is that it tracks a vehicle from one region to any other region on the scene. This makes the system very accurate and efficient for turning movement determination at intersections.

Tulip: This is a primitive system and the first image processing system used for traffic monitoring. There has been not much improvement or modification in the system since its introduction. The system is very poor as compared to the other systems discussed above. The system has a limited capacity of analyzing only one lane at a time and is not suitable for field implementation. The results of counts and speeds are often underestimated. It requires a IBM compatible AT computer to perform computations and the process of initialization is very easy and straightforward.

2.4 Autoscope

The general need for a wide area multispot detection lead to the development of the Autoscope at the University of Minnesota. Financial support was provided by the FHWA and Minnesota Department of Transportation. Autoscope is a multispot wide area detection system that can detect traffic in many locations within the camera's field of view. The Autoscope system can be described by dividing it into the following major components based on their respective function:

System Functions. The Autoscope system can detect vehicle presence in different regions within the field of the camera's view i.e., it can measure traffic parameters in more than one lane at any time. It can operate with a total of 22 presence detectors for extracting traffic data from one scene. There is no directional restriction on the detectors i.e., there is no effect of the direction of traffic movement on the detection process.

A separate PC with a digitizer card and a compatible RGB monitor are required as a supervisor unit during the initialization process. The supervisor program runs under Windows 3.0.

Principle of Detection The principle involved for detection is known as the tripwire detection method. In this method a small band of pixels corresponding to a small width of lane will reflect the movement of vehicles on that lane instead of considering all pixels corresponding to that lane. This band of pixels describing the detection zone records any change in light intensity in the background due to a passing vehicle as a detection. The data are stored in the form of the detector number, time of detector activation, and the duration of activation. These detectors, in the form of straight lines, can be placed anywhere on the TV monitor displaying the traffic scene, and with any orientation. The detector locations are specified by the user using interactive graphics and can be changed as often as desired [6].

The basic format of the detector data can be manipulated to extract different traffic parameters like flow, speed, density, etc. In the following chapters it has been shown how the detector data along with the detector layout pattern and camera alignment can be used to measure truck dimensions at a port-of-entry.

Hardware. The Autoscope system is a 9" by 9" by 18" inch black box with a provision for a video input and power source. The system has a RAM card for storing configuration data when the system is switched off. Each system can accept one video input from one surveillance camera at any time. However the latest version has been expanded to adopt multiple camera units. During the initialization process a separate personal computer with a Matrox frame grabber card and compatible RGB monitor is required.

Software. The Autoscope data can be automatically processed by the supervisor software to give traffic parameters. The software, which operates under Windows 3.x, computes flow rate, occupancy, density, frequency, etc. Extensive work is being conducted at different institutions for evaluating the application of Autoscope for different parameter extraction and development of subsequent software for analyzing the respective data. The Civil Engineering Department at the University of Idaho recently developed software for determining the turning movements at intersections using Autoscope generated data.

Other refinements are for defining detector parameters like eliminating the effect of vehicle shadows, for improving detection during night/day transition phase, setting sensitivity limits for detectors, and setting persistence limits for detectors. Depending on camera alignment and position of sun on the sky, large vehicle shadows are formed which extend into the adjacent lanes that are simultaneously detected as passing vehicles by the detectors in that lane. This effect has been effectively reduced by developing the shadow algorithm. The parameters for each detector have to be defined based on the direction of vehicle movement and position of shadow. Most of the overdetections are during the day/night transition phase. This is because of the change in the light intensity during this period. The algorithm developed is not very effective in eliminating this problem. However, the new version of the Autoscope system has reduced this problem. A number of the other problems in the older version (Model 2002) have been very effectively reduced in the new system (Model 2003).

Initialization Process The initialization process consists of two modes: Setup Mode and Control Panel

Mode.

Setup Mode: In the setup mode, detection zones are defined in the form of horizontal or vertical lines using interactive graphics that can be changed or modified to suit different site conditions. In this mode the detector parameters like sensitivity, persistence, shadow algorithm option, and day/night transition option for each individual detector can be defined.

Control Panel Mode The Autoscope collects data in this mode. This mode consists of two sub-modes: configure mode and detect mode. In the configure mode, the detector file created and saved in setup mode can be downloaded to the Autoscope. Autoscope begins collection of data (i.e. detection of vehicles) when it is placed in detect mode. There is an option for saving the data in two forms, by time slice and detection data. The time slice data saves the flow, occupancy, and headway for one minute time intervals. The detection data consists of the detector number, time of detector activation, and the duration of detector activation. This general format detector data can be manipulated and used for different traffic data extraction like vehicle dimensions. This is discussed later in this report.

2.5 Applications of Image Processing

There have been several important research projects testing the use of image processing technology for transportation data collection. Most of this research has been done to show the multiple traffic data collection capabilities of the newly developed image processing systems. The most common applications in traffic data collection involve volume counts, speed measurements, density measurements, turning movements counts, headway measurements, vehicle classification, vehicle tracking, origin-destination patterns, and measurement of vehicle dimensions. Various types of detection algorithms have been developed and field tested.

At the Environmental Research Institute of Michigan (ERIM), Gilbert and Holmes have developed real time image processing algorithms for detecting and tracking vehicles in actual traffic settings [8]. The principle used for detecting a vehicle is the comparison of the difference in illumination of a defined region on scene by a passing vehicle i.e., the background color of the scene is taken as the standard of reference and any passing object with a different light intensity or color is detected as a vehicle.

Vieren and group have used "frame differencing" to define the edges of moving vehicles in successive frames [7]. This method is insensitive to variations in illumination of the scene [7].

I.K. Sethi and L. Brillhart have employed image processing technology to detect the nonconforming behavior of vehicles on roadways in addition to providing normal traffic statistics for traffic monitoring [5]. They have used frame differencing between consecutive frames and identified centroids of vehicles for tracking.

The Australian Road Research Board (ARRB) has adopted the Video Detection Data Acquisition System (VADAS) for traffic data collection. VADAS can be used to define a maximum of 16 detection points on the TV screen, and any change in background light intensity of these points is recorded in the form of the number of the detection point and the time of activation. R.J. Troutbeck and J.S. Dods have used VADAS with video data collected from cameras mounted on a 10m high telescopic mast [1]. By manipulating the data output they have determined vehicle manoeuvres and paths. Also through ARRB, Taylor and others have used VADAS for headway and speed data collection on freeways and parking lots [2]. The measured speed by this technique was compared with the speed obtained using radar gun, which shows significant potential in image processing technology for speed measurement.

Two studies have been completed recently to evaluate the currently available image processing technologies for highway operations [4,9]. One study at the University of California at Berkeley has described the components, advantages, and disadvantages of image processing technology for traffic data collection [4]. The California Polytechnic State University conducted a study for the California Transportation Department to evaluate the feasibility of implementation and performance characteristics of available and under-development stage image processing technologies [9]. This study identified eight systems having good potential for analyzing traffic data. The results in terms of efficiency for measuring different traffic parameters under different site conditions like congested flow, fog, snow, rain, night time, and poor lighting conditions were analyzed and the advantages and disadvantages of each system over the other were evaluated.

In a recent study at the University of Minnesota, the Autoscope system has been evaluated for incident detection on a freeway. The system is known as IDEAS, for Incident Detection Evaluation through the Autoscope System [6]. In this study, a 38 camera, 3.5 mile machine vision live laboratory was designed on Interstate 394 for deployment and validation of the incident detection system [6]. The purpose of IDEAS is to provide advanced information on incidents so that traffic management personnel can take corrective action. Special algorithms have been developed and incorporated into the system for this purpose. The results from this experiment indicate a false alarm rate of only three percent. This indicates the level of efficiency of the Autoscope system in field implementation for detecting incidents.

This range of capabilities of image processing technologies establish their importance in developing and implementing IVHS technology.

The application of image processing has been extended to evaluate the pavement surface distress like cracks, potholes, depressions, etc. NCHRP Project 1-27 was initiated in response to this need [13]. The objective of the research was to develop a system for processing video images to identify, quantify, and classify pavement distress in terms of types, severity, and extent [13]. The results have shown an error of only 5 to 17 percent, and in some instances it proved to be superior to the visual inspection method currently practiced by the personnel in this field. The image processing system was very sensitive and was able to measure cracks with very small openings.

In another paper presented at the annual TRB 1991 meeting, H.N. Koutsopoulos and I.M. El Sanhouri of the Massachusetts Institute of Technology have shown a method for automatic interpretation of asphalt pavement distresses, recorded on video or photographic film, with emphasis on segmentation and classification of digitized distress pavement images [15]. Segmentation is the process of extracting objects of interest from the background, in this case the pavement distresses like cracks, potholes, etc., and classification is the process of identification of distress type. The preliminary results from this study indicate that it is feasible to automate the process of pavement image analysis.

Another diverse application of image processing was demonstrated in paper presented during the annual TRB meeting in January 1992 [14]. Y. Lu and others have illustrated the application of image processing for measuring pedestrian volumes at intersections. They have developed a TV image sequence analysis based algorithm that automatically counts the number of pedestrians on crosswalks in daytime periods and automatically determines their volume [14]. The tripwire method of detection is employed for this purpose. A band of pixels on the TV image corresponding to the cross walk are placed perpendicular to the direction of pedestrian movement by the user. It is similar to the detector in the Autoscope. The results have shown 94% accuracy in the pedestrian volume measurements. However there is a problem with this pattern of detector placement, i.e., if more than one pedestrian walks together side by side then the detector will detect them as one.

2.6 Advantages Over Conventional Systems

The method of data collection using video cameras has many advantages over conventional methods like pneumatic switches, treadle and infrared detectors. The use of video cameras allows for unobtrusive data collection and since the detectors are not placed physically on the road, the maintenance work needed for loop detectors is eliminated. Using video cameras for collecting traffic data has made this process less laborious, more flexible, and less costly. An added advantage is the permanent record of data that can be stored for future reference. In traffic management applications it is required to know the aggregate behavior of traffic in a particular roadway section rather than at a point. Conventional methods provide point measurements of parameters whereas a video camera can give additional information about the whole segment such as qualitative traffic flow conditions, queue characteristics, vehicle movement at intersection, and vehicle identification and classification.

2.7 Limitations and Disadvantages

There are a few technical problems associated with image processing. Most of the systems tested have shown poor performance under changing lighting conditions (day/night transition phase), fog, and snow. Image processing uses the principle of the difference in color or light intensity between the object and the background color or light pattern to detect a vehicle. Therefore, any vehicle having a color or light intensity similar to the background color cannot be detected. Another disadvantage is in terms of memory constraints and processing time. As described earlier, the memory required is very high for a detection zone covering the whole TV screen. But ideal results can be obtained by considering the total TV screen as a detection zone. These technical problems can be eliminated with time with the invention of faster systems and those with larger storage. Another problem associated with this technology is the effect of occlusion and effect of shadows of vehicles. The effect of occlusion can be defined in terms of missed detections of vehicles that are hidden behind large trucks or other vehicles. This problem can be eliminated by adjusting the camera position. The shadows of vehicles cause overdetection i.e., the shadows are detected as individual vehicles. This problem has been eliminated to a considerable level in some of the image processing technologies by developing advanced algorithms.

Other limitations are in terms of institutional barriers, equipment cost, development of standards, and the size of the market. Public acceptance is needed in order to use video cameras to monitor freeways and arterials. Although the cost of equipment is low, the complete replacement of conventional systems might be very expensive. An average of two to four cameras are needed to monitor a one mile roadway section. This might limit the use of image processing equipment to selected locations. Conventional loop detector technology currently dominates the market and is cost effective. Therefore, there might be some resistance to the introduction of image processing technology in the marketplace. Clearly, though, two things will be true: technology will improve and cost will decrease.

CHAPTER 3. TRUCK HEIGHT MEASUREMENT

3.1 Introduction

The purpose of this chapter is to describe the field test that was conducted to determine the feasibility of using Autoscope to measure the height of trucks at a port of entry and to describe the results of the analysis of the truck height data.

3.2 Method of Data Collection

The field data were collected by a video camera recording the trucks passing through the Lewiston port of entry. The truck heights were measured manually and all trucks were numbered (i.e. a number was temporarily placed on the side of the truck) before passing the camera. Data were collected for a total of 79 trucks, representing a variety of kinds of truck types. Reference points at one foot spacing were marked on a utility pole using colored tape as a guide for locating video detectors.

3.3 Autoscope Data Analysis

Alternative video detector alignments to detect the passage of the trucks were studied. The selection of the best detector configuration and suitable background for plotting detectors was somewhat complicated. At first, detectors at half foot spacing were plotted against the sky background. But this resulted in problems due to both the close detector spacing and placement of the detectors against sky. Closely spaced detectors seemed to be activated without any passing vehicle. After several trials, it was determined that a minimum spacing of one foot reduced this problem significantly. The detectors were also sensitive to slight changes in sky color and flickered if placed against the sky background for no apparent reason. The final detector configuration consisted of reducing the size of horizontal detectors so that they did not protrude into the sky background and fit only on the signal post. This final detector grid was used for height estimation.

The method of similar triangles was used to measure the height of the truck based on the detector activated by the highest point on the truck. Figure 1 shows the principle and method involved in the height computation. The path of the truck in the figure is the exact point where the height was computed.

In addition, all site measurements such as camera height, horizontal distances, and height of the reference grid on the signal post above the ground were made during the field data collection.

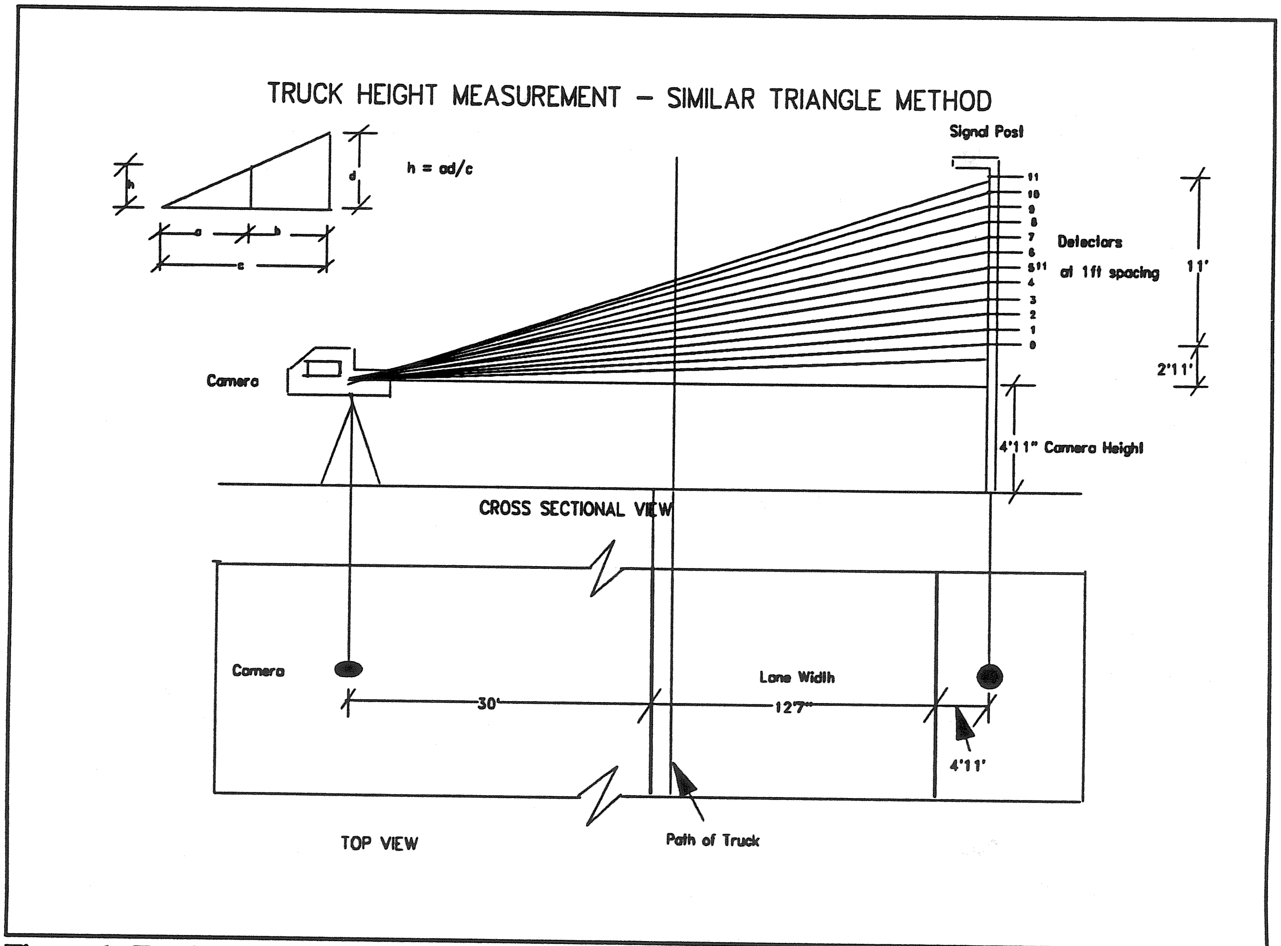

Figure 1. Truck Height Measurement Method

3.4 Truck Profiles and Visual Images

Each time a truck passes through the video detector grid it activates a set or patterns of detectors depending on the shape and height of the truck. The Autoscope data, consisting of detector number, time of activation, and the duration of activation for each truck, was utilized to construct a visual representation of the truck shape. The result of this plot is a profile or representation of the visual image of the truck. Sample plots for two trucks are shown in Figures 2 and 3. The shape of the truck components, both the cab and the trailer, are clearly visible in the two figures for each truck.

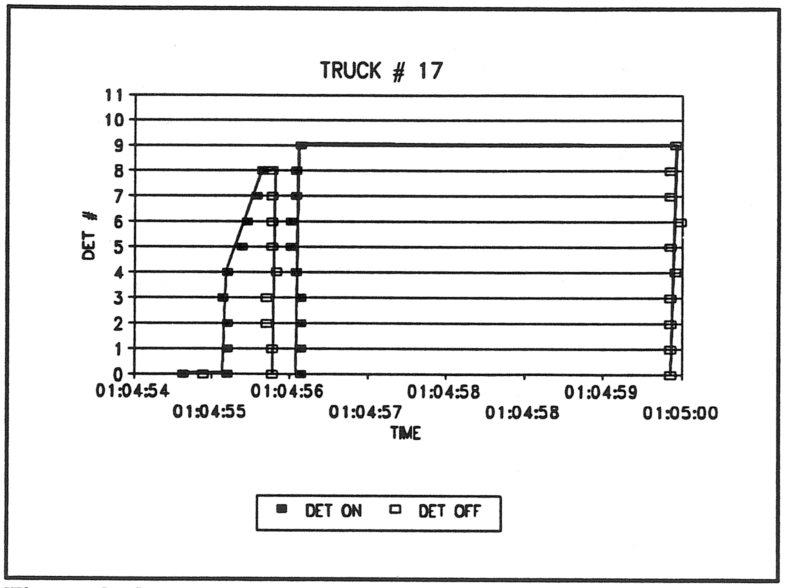

Figure 2. Sample Truck Profile

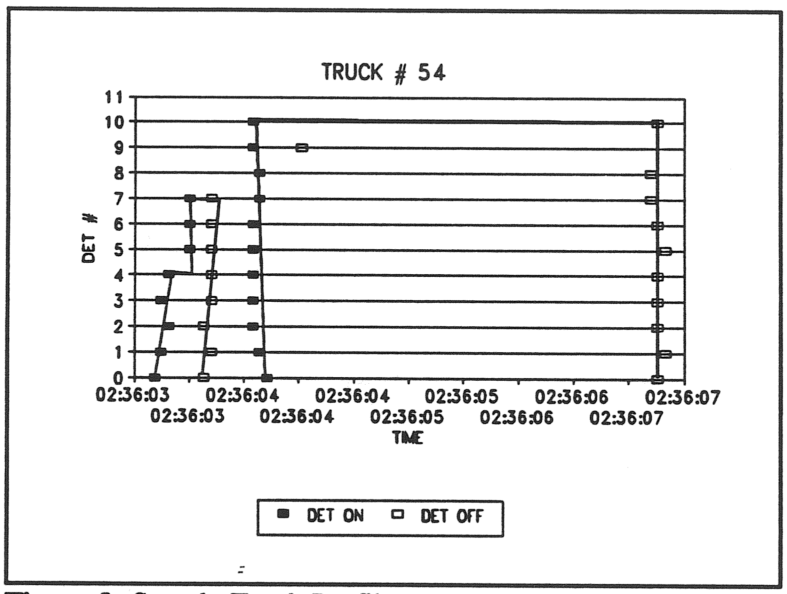

Figure 3. Sample Truck Profile

3.5 Autoscope Height Estimates

The field measured truck height data, as well as the heights estimated using the Autoscope system, are given in Tables 1 and 2. The percent error of the Autoscope estimate is also given in the tables. Note that the accuracy of the Autoscope height estimate is limited by the one-foot spacing of the video detectors.

Table 1. Truck Height Data

TRUCK #	MEASURED HEIGHT	AUTOSCOPE HEIGHT	PERCENT ERROR	TRUCK #	MEASURED HEIGHT	AUTOSCOPE HEIGHT	PERCENT ERROR
1	12.80	13.07	-2.1%	41	11.20	10.38	7.4%
2	9.90	9.70	2.1%	42	13.40	13.07	2.5%
3	8.70	8.36	4.0%	43	10.50	10.38	1.2%
4	13.40	13.07	2.5%	44	13.20	13.75	-4.1%
5	13.10	13.07	0.3%	45	10.20	10.38	-1.7%
6	13.00	11.72	9.9%	46	13.20	12.40	6.1%
7	10.20	10.38	-1.7%	47	11.10	11.05	0.5%
8	13.20	13.07	1.0%	48	9.90	10.38	-4.8%
9	10.00	10.38	-3.8%	49	13.10	12.40	5.4%
10	13.20	13.07	1.0%	50	13.40	12.40	7.5%
11	13.10	13.07	0.3%	51	13.70	13.07	4.6%
12	12.00	11.72	2.4%	52	13.20	13.07	1.0%
13	11.70	12.40	-5.9%	53	9.50	10.38	-9.2%
14	13.30	12.40	6.8%	54	13.30	13.07	1.8%
15	11.10	11.72	-5.5%	55	13.30	13.07	1.8%
16	9.90	9.70	2.1%	56	8.70	11.05	-27.0%
17	13.30	12.40	6.8%	57	13.10	13.07	0.3%
18	13.30	12.40	6.8%	58	13.00	11.72	9.9%
19	9.00	10.38	-15.3%	59	13.30	12.40	6.8%
20	9.50	11.72	-23.3%	60	12.70	11.05	13.0%

Table 2. Truck Height Data

TRUCK #	MEASURED HEIGHT	AUTOSCOPE HEIGHT	PERCENT ERROR	TRUCK #	MEASURED HEIGHT	AUTOSCOPE HEIGHT	PERCENT ERROR
21	10.70	10.38	3.0%	61	9.60	9.70	-1.0%
22	13.40	13.07	2.5%	62	13.50	13.07	3.2%
23	10.20	10.38	-1.7%	63	13.20	13.07	1.0%
24	13.00	12.40	4.6%	64	11.90	11.72	1.5%
25	10.20	10.38	-1.7%	65	13.40	12.40	7.5%
26	8.20	10.38	-26.5%	66	9.20	9.70	-5.4%
27	10.00	11.05	-10.5%	67	13.30	12.40	6.8%
28	11.70	11.72	-0.1%	68	13.30	12.40	6.8%
29	11.80	10.38	12.1%	69	9.50	10.38	-9.2%
30	10.20	9.70	4.9%	70	8.80	10.38	-17.9%
31	11.10	11.05	0.5%	71	13.70	13.75	-0.3%
32	9.70	11.05	-13.9%	72	9.00	11.05	-22.7%
33	11.50	11.72	-1.9%	73	12.30	11.72	4.7%
34	12.70	12.40	2.4%	74	13.10	12.40	5.4%
35	10.00	9.03	9.7%	75	13.30	13.75	-3.4%
36	10.40	10.38	0.2%	76	9.80	9.70	1.1%
37	13.30	13.75	-3.4%	77	12.90	13.07	-1.3%
38	13.40	12.40	7.5%	78	12.90	12.40	3.9%
39	8.80	11.05	-25.5%	79	13.20	13.75	-4.1%
40	13.60	13.07	3.9%				

Two factors have been observed that seem to explain the under and over estimation of truck heights by Autoscope, the color of the truck and the shape of the truck.

Effect of Color. The detectors placed on the television monitor are activated if there is any change in color or light intensity in the background. If the detectors are placed against a white colored surface or object they are activated due to any change in color except white; similarly, if they are placed against a black colored background they are activated by any color except black. In this case all or some portion of the trucks had colors similar to the detector background color, resulting in the non-activation of some detectors. This leads to the underestimation of truck heights. The error of underestimation can be attributed to this factor.

Error in field measurement. The Autoscope height estimation is based on the detector activated by the highest point on the truck. The manual measurements are usually of the back portion of the truck i.e., not of the cabin unless the truck is empty or is without any load. But for some trucks, the cabin height is greater than the back portion. In this case the Autoscope estimated height, which is of the cabin, results in overestimation when compared to manual measurements. Some trucks have their exhaust pipes protruding above the cabin and this represent the highest point on the truck. In this case, the Autoscope estimated height is of the exhaust pipe, which is also an overestimation when compared to the manually measured height.

3.6 Statistical Analysis of Results

Graphical Data Comparison. Scatter plots of the Autoscope detected height vs the actual measured height are given in Figures 4 and 5. Figure 5 represents the same data as Figure 4, except excluding the estimated heights with the highest errors. The points above the diagonal line represent underestimated heights and the points below the line indicate overestimated heights.

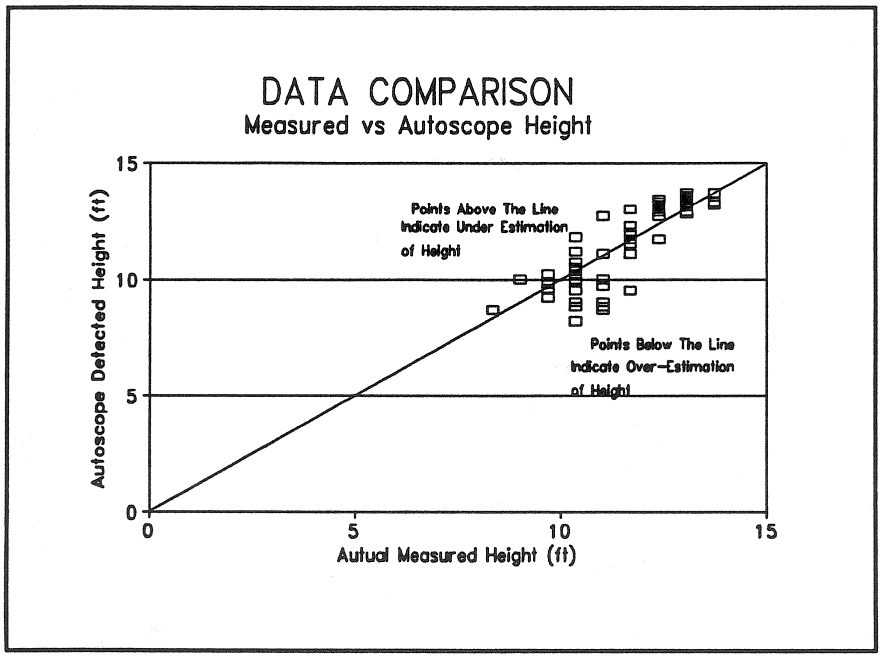

Figure 4

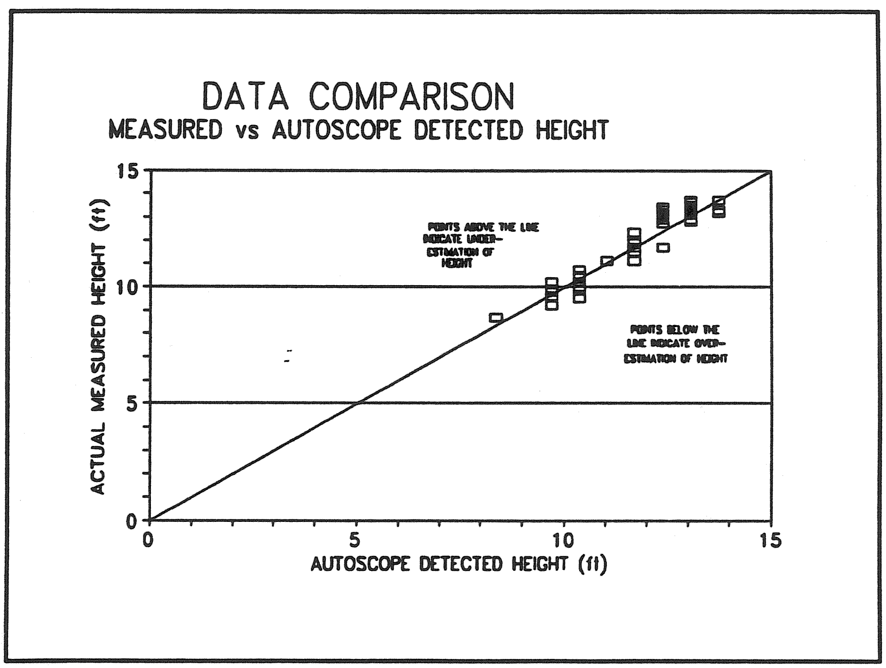

Figure 5

Figure 6 shows the histogram of the distribution of the measurement errors. It is observed that 70 of the 79 trucks have measurement errors less than 10%.

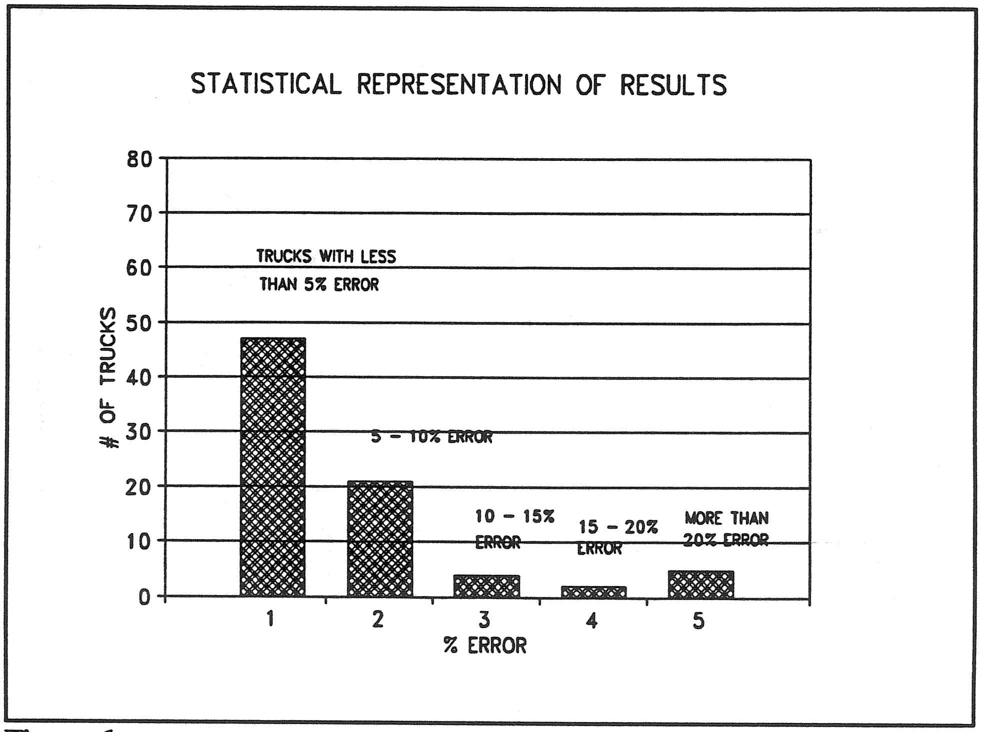

Figure 6

The trucks with maximum percent error (greater than 10%) are given in Table 3 along with the possible reasons for the error.

Table 3. Assessment of Measurement Errors

CAUSE OF ERROR	ERROR TYPE	TRUCKS AFFECTED
The height detected is of the cabin which is larger than the trailer height	Overestimation	19
The height indicated is of the exhaust pipe	Overestimation	20, 26, 72
The height indicated is of the front portion	Overestimation	27, 32, 39, 56, 69, 70
Effect of color	Underestimation	6, 38, 50, 58
Effect of shape	Underestimation	35, 60
Effect of color and shape	Underestimation	29

3.7 Statistical Tests

A paired t-test was completed to determine the statistical correlation between the Autoscope measurements and the field data. The truck heights measured by Autoscope were compared to the manually measured heights using this procedure. Table 4 summarizes the results of the t-test.

Table 4. Statistical Test

Stat. Parameters	Measured Height	Autoscope Height
Mean	11.73	11.70
Standard Deviation	1.69	1.30
Variance	2.84	1.70
Minimum	8.2	8.36
Maximum	13.7	13.75
Mode	13.1	13.07
Median	12.7	11.72

Paired t-test:
H_0: Difference of means = 0
H_a: Difference of means is not equal to 0
T.S: $t_{computed}$ = 0.25222
For a p-value of 0.05, by applying a two tailed test, t_{table} = 1.99366

It can be concluded that since the computed t value is less than the t table value, the null hypothesis cannot be rejected that the two means are equal. Therefore it implies that statistically there is no difference between the manually measured truck heights and Autoscope measured truck heights. This is a good indication of the accuracy of the Autoscope measurements.

3.8 Summary/Conclusions

The truck height measurement results are very encouraging. The measurement error rate is less than five percent for most of the trucks measured. This indicates that Autoscope has the potential to be used for accurate truck height measurements. Most of the inaccuracies are due to site conditions, inaccurate field measurements, and the shape or color of the trucks.

Detector activation problems were also encountered. The detectors flicker if plotted against a sky background due to differences in or varying lighting conditions. This problem can be easily eliminated by ensuring that a proper background exists for the videotaping of the truck movements.

CHAPTER 4. TRUCK LENGTH MEASUREMENTS

4.1 Introduction

The purpose of this chapter is to describe the field test that was conducted to determine the feasibility of using Autoscope to measure the length of trucks at a port of entry and to describe the results of the analysis of the truck length data. Two methods were used to measure the lengths of trucks passing through the port-of-entry using the Autoscope data: the *truck progression method* and the *truck speed method*. The results of each method were compared with the data collected using standard manual field measurement methods.

4.2 Truck Progression Method

In this method, video detectors are plotted at fixed known distance apart on the television monitor; Autoscope is used to generate detector activation and duration times. See Figure 7.

The data are plotted on a time-distance diagram to indicate the progression of each truck through the detector chain. The length of each truck can be estimated by measuring the distance between a detector chain that is simultaneously activated at any given time. Examples of this procedure are given in Figures 8 and 9.

The measurement results are given in Table 5. While the measurement principle described above is correct, the errors shown in Table 5 can be attributed to the difficulty of resolving the image geometry and the actual site dimensions. The major reason for this problem is that all detectors were placed to the left of the camera, thus exagerating image geometry problems. More careful camera placement and geometry measurement should greatly reduce these errors.

On the positive side, it should be noted that a plot of the number of detectors activated vs the field measured truck length does show a very strongly correlated relationship. The correlation coefficient between the actual length of the truck and the number of simultaneously activated detectors is 0.85. A plot of this relationshiop is shown in Figure 10.

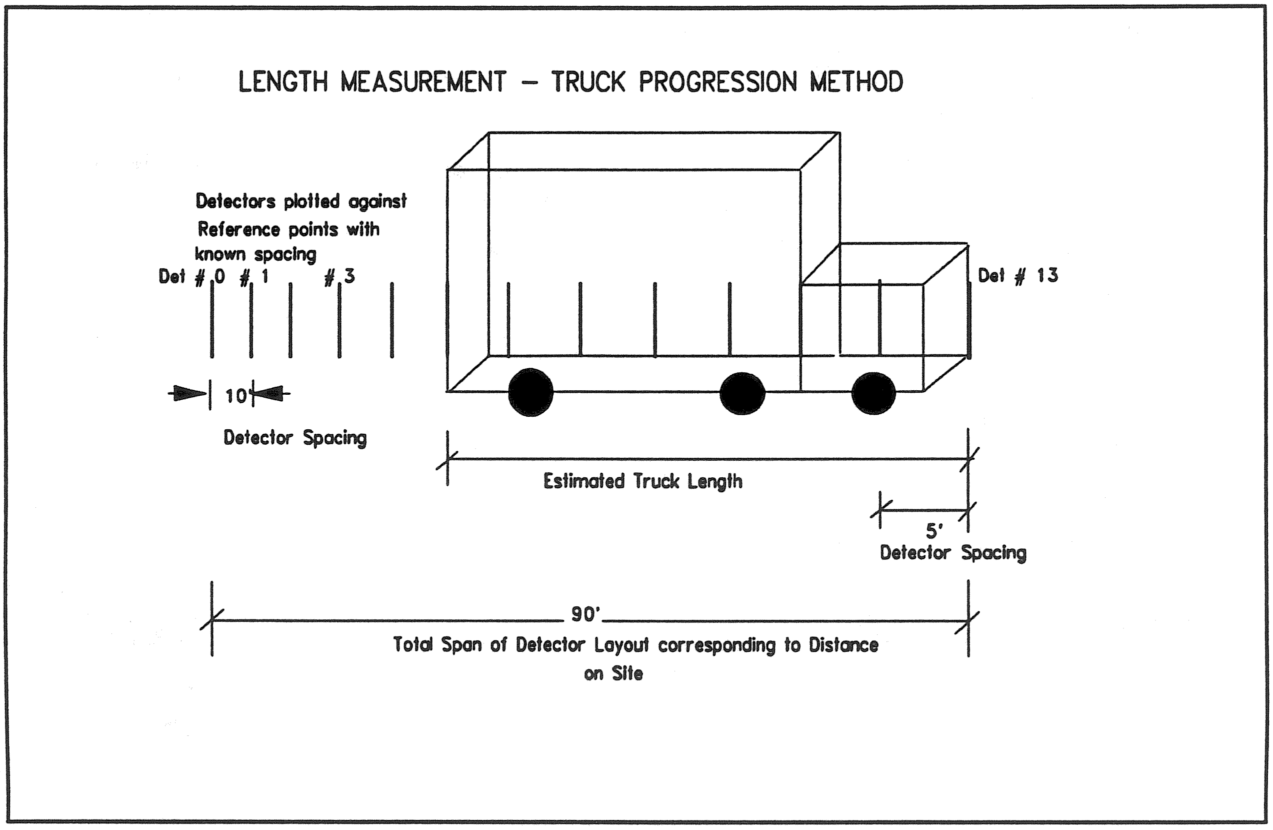

Figure 7. Truck Progression Method

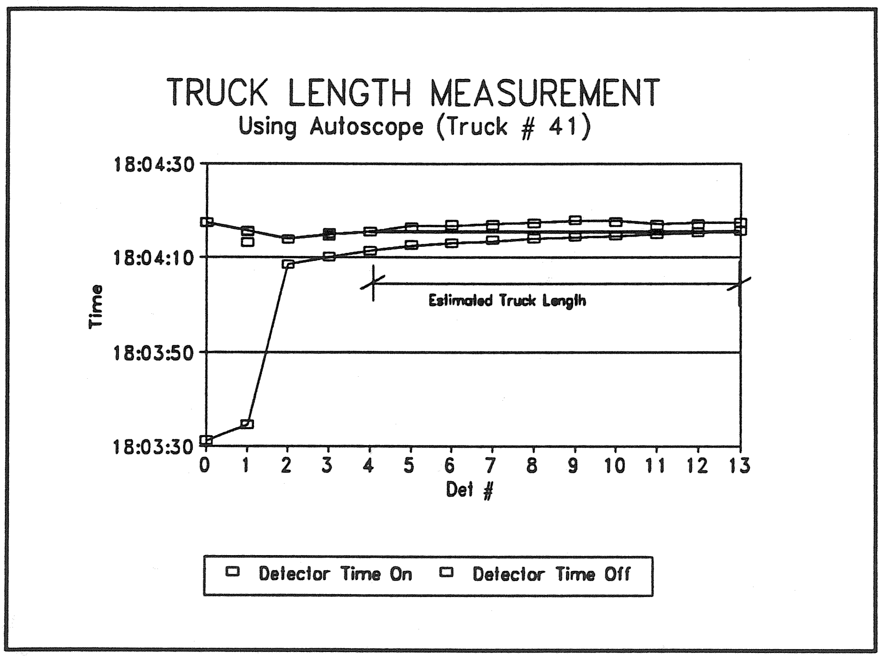

Figure 8. Truck Length Measurement

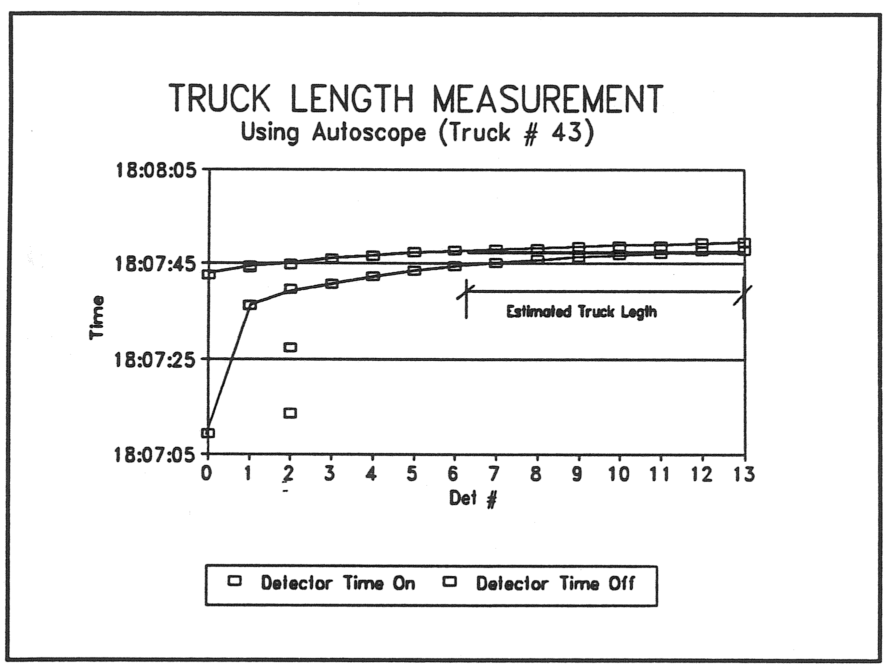

Figure 9. Truck Length Measurement

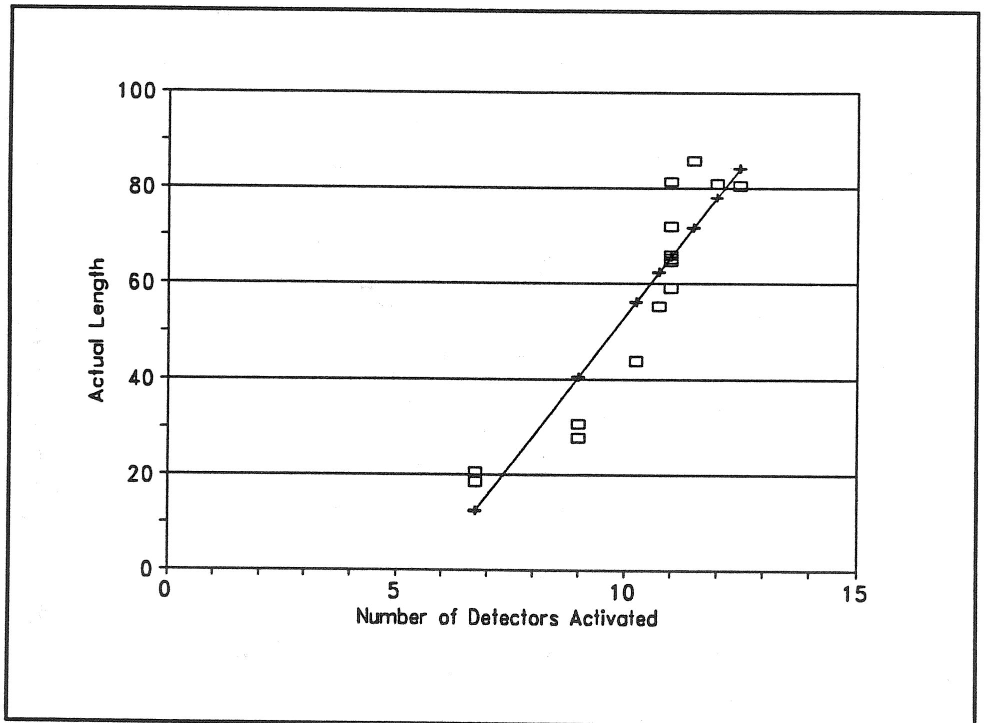

Figure 10. Measured Truck Length vs Number of Activated Detectors

Table 5. Truck Length Data Using Truck Progression Method

TRUCK	ACTUAL LENGTH	NUMBER OF SIMULTANEOUS DETECTORS	COMPUTED LENGTH	PERCENT ERROR
32	80.8	12	53.92	33.27
33	20.6	6.75	22.75	-10.42
34	80.5	12.5	57.29	28.83
35	71.9	11	47.18	34.38
36	81.4	11	47.18	42.04
37	65.8	11	47.18	28.30
39	55.2	10.75	45.50	17.58
40	64.7	11	47.18	27.08
41	27.8	9	33.70	-21.22
42	64.7	11	47.18	27.08
43	18.5	6.75	22.75	-22.96
44	65.1	11	47.18	27.53
46	59.1	11	47.18	20.17
47	30.6	9	33.70	-10.13
48	85.7	11.5	50.55	41.02
49	43.8	10.25	42.13	3.82
50	65.8	11	47.18	28.30

4.3 Truck Speed Method

In this method, the videotape previously used for height detection is studied. The method consists of finding the speed of the truck when it passes through two detectors spaced at a known distance, and calculating the length based on the duration of detector activation. The equation used is:

$$L = \frac{sd}{\Delta t} \tag{1}$$

where L is the length of the vehicle, s is the detector spacing, d is the duration of detector activation, and Δt is the difference in time of activation between the two detectors. The equation is very sensitive to the difference in time of activation, a very small value. This value decreases as the speed of the vehicle increases. The equation assumes a constant speed of vehicles while traversing the detector grid. Thus, the detectors should be highly sensitive to record this small difference in time. The principle applied is very accurate, but the results have indicated problems in either the sensitivity of the Autoscope detectors, or in the measured spacing between the two detectors. Since the detector spacings used in this method were not accurately measured in the field during the on-site data collection and videotaping, most of the error can be attributed to this latter cause.

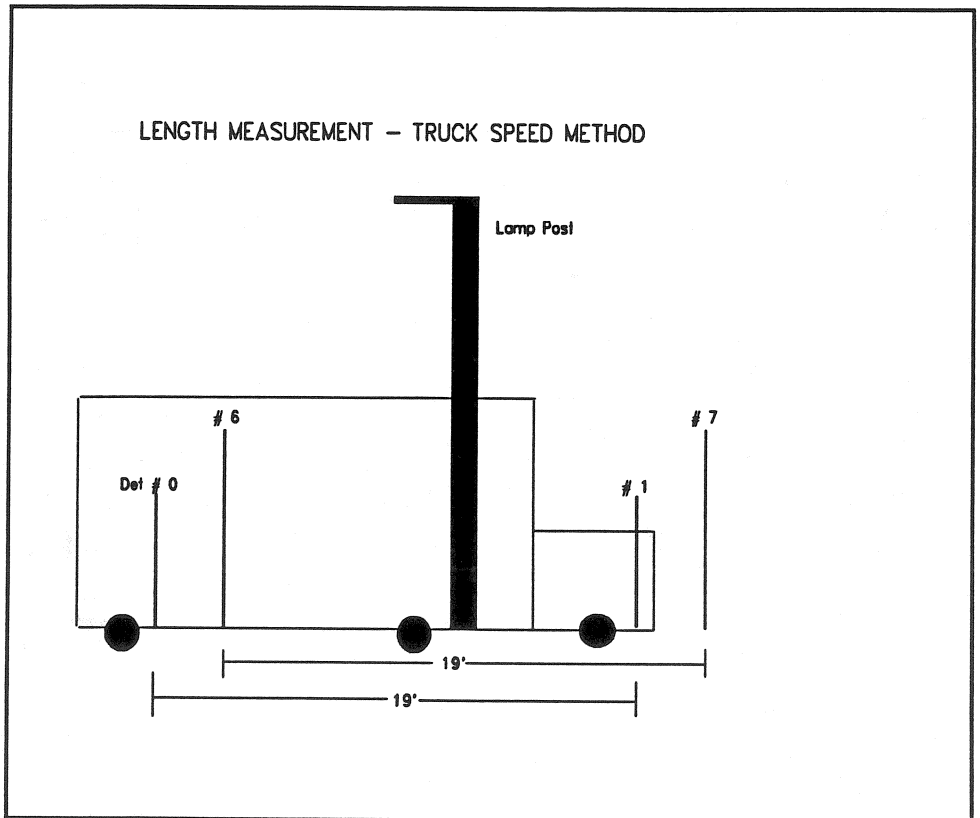

Figure 11. Truck Speed Method

Table 6. Length Estimates Using The Truck Speed Method

TRUCK #	ACTUAL LENGTH	DETECTED LENGTH							
		DET # 0	% ERR	DET # 1	% ERR	DET # 6	% ERR	DET # 7	% ERR
32	80.8	65.56	18.87	54.14	32.99	130.70	-61.76	124.75	-54.40
34	80.5	110.56	-37.34	101.38	-25.94	119.97	-49.04	111.03	-37.93
35	71.9	70.30	2.22	59.15	17.73	56.03	22.07	51.65	28.17
36	81.4	56.03	31.16	49.68	38.97	56.43	30.67	50.83	37.56
37	65.8	57.02	13.35	53.24	19.09	65.76	0.06	62.59	4.88
38	64.2	60.37	5.96	48.08	25.12	59.77	6.90	52.26	18.60
39	55.2	48.88	11.44	43.52	21.16	85.55	-54.98	86.83	-57.29
40	64.7	66.54	-2.84	53.15	17.85	103.23	-59.55	102.23	-58.01
41	27.8	28.27	-1.68	18.49	33.49	28.70	-3.25	24.44	12.10
42	64.7	60.85	5.96	55.53	14.18	56.11	13.28	59.25	8.42
43	18.5	39.23	-112.06	24.60	-32.99	67.20	-263.24	64.00	-245.95
44	65.1	60.74	6.69	53.64	17.60	143.71	-120.75	155.05	-138.18
45	73.4	69.46	5.36	57.44	21.74	65.09	11.32	56.66	22.80
46	59.1	51.46	12.93	43.81	25.87	157.78	-166.97	189.39	-220.45
47	30.6	47.54	-55.37	36.57	-19.51	40.73	-33.10	32.00	-4.58
48	85.7	74.26	13.35	73.65	14.06	129.40	-51.00	122.54	-42.98
49	43.8	33.55	23.40	27.64	36.90	201.31	-359.61	258.91	-491.12
50	65.8	56.53	14.08	52.75	19.83	111.90	-70.07	116.17	-76.55

Note: **Four *detected* length data sets are presented abouve. The detector number cited notes the detector used to calculate the duration of the truck passage. The detector pairs used to compute travel time are detectors 1 and 2 and detectors 6 and 7.**

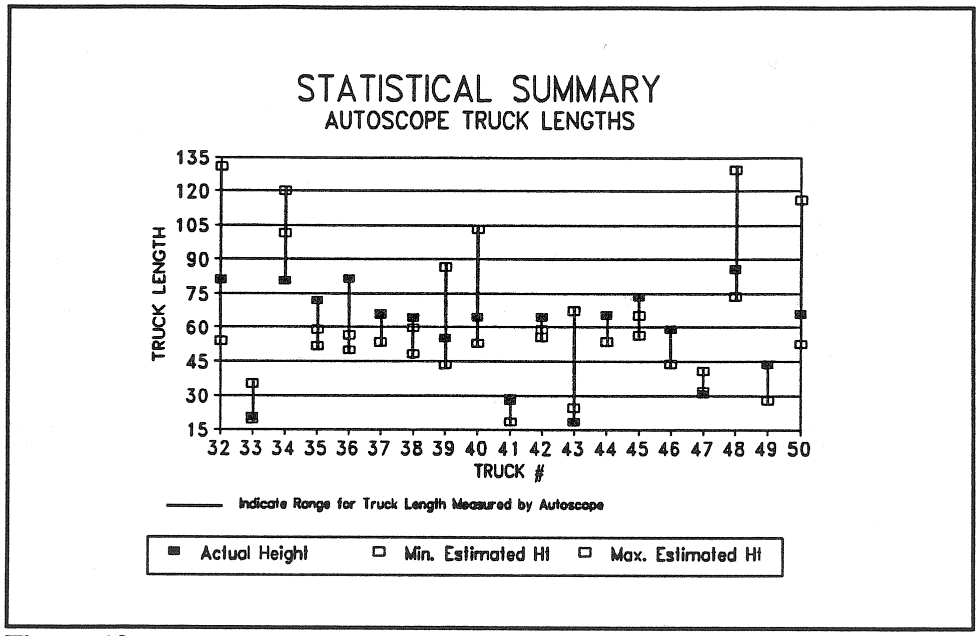
STATISTICAL SUMMARY
AUTOSCOPE TRUCK LENGTHS
TRUCK LENGTH
135
120
105
90
75
60
45
30
15
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
TRUCK #
Indicate Range for Truck Length Measured by Autoscope
Actual Height
Min. Estimated Ht
Max. Estimated Ht

Figure 12

4.4 Statistical Tests

A paired t test was performed on the data to determine if the correlation between the Autoscope measurements and the field measurements was significant. The results are shown in Table 3.

Table 7. Statistical Tests

Statistic	Actual	Computed	Difference
Mean	57.76 (Act)	34.97 (Comp)	22.79 (for Diff)
Standard Dev.	21.18	5.28	16.43
Variance	448.68	27.87	269.97
Min. Value	18.5	22.74	-4.24
Max Value	85.7	42.11	46.96

Paired t-test:

H_o: Difference of means = 0
H_a: Difference of means is not equal to 0
T.S: t = 5.7196
for a p-value of 0.05 and n= 17, t_{table} = 2.12

Since the computed t-value is greater than the t-table value, the hypothesis can be rejected that there is no difference in the values. Therefore it indicates that the computed and the measured lengths are not the same.

4.5 Summary/Conclusions

The results obtained for Truck length measurements were the least accurate of various tests conducted. The primary reason was the camera position (i.e. the cameras line of sight) while recording data. The video recording intended to measure truck length was done using camera inclined at an angle to the lane of traffic i.e., its line of sight of camera was not perpendicular to lane direction. This gives a diagonal estimate of the length of the truck but not the actual length. Another method used to measure the truck lengths depended on the determination of the speed of trucks by measuring the time it takes to travel between two detectors spaced at known distance. This is a very accurate method if the Autoscope speed measurements are accurate. The results obtained using this method, however, were also not satisfactory.

It should be pointed out that the site geometry and camera angle were probably the most important factors here causing the large errors. Additional work on site planning and camera location is needed in order for these methods to become effective.

CHAPTER 5. TRUCK WIDTH MEASUREMENT

5.1 Introduction

The width of trucks is a very important vehicle dimension parameter. It is an important parameter to know so that oversize trucks which might cause traffic hazards can be identified. Currently, ITD staff manually measure truck widths to determine if they are within legal standards. This is tedious, time consuming, and requires extra labor. The purpose of this chapter is to present the results of a test to automatically measure truck width using Autoscope. Since the width can be either measured from the front or the top, two alignments of the camera can be used to give the same results. The best alignment is with the camera placed on top of the truck lane with a slight inclination towards the direction of movement. With this alignment all the three parameters of interest (i.e., height, length, and width) can be measured at the same time or from the same scene.

5.2 Method of Data Collection

Video data were collected from an elevated location from the side of the lane. This provided a top view of the truck lane. The Clark Mast was used for holding the camera at the elevated position. A camera mount system can be fixed on top of the mast which accommodates two cameras at one time. One camera was mounted on the Mast yielding a top view of the truck lane. Another camera was placed on the ground with the camera aimed straight across to the truck lane. Reference marks with a colored tape were placed on the pavement at known spacing and all geometric measurements relative to the site were noted. The widths of all trucks video recorded were measured manually to validate the Autoscope capability for width estimation.

Data were collected using two different alignments of the camera mounted on the Clark Mast. One alignment was at a small angle in the vertical plane, while the other was at a large angle measured from the horizontal plane. As the angle of inclination is increased the coverage of the scene below becomes better or more compatible for Autoscope analysis, and the horizontal distances to be measured on ground become smaller. The video data collected from the steeper camera alignment was found suitable for data analysis using Autoscope. Figure 13 shows the camera alignment and the method of width computation.

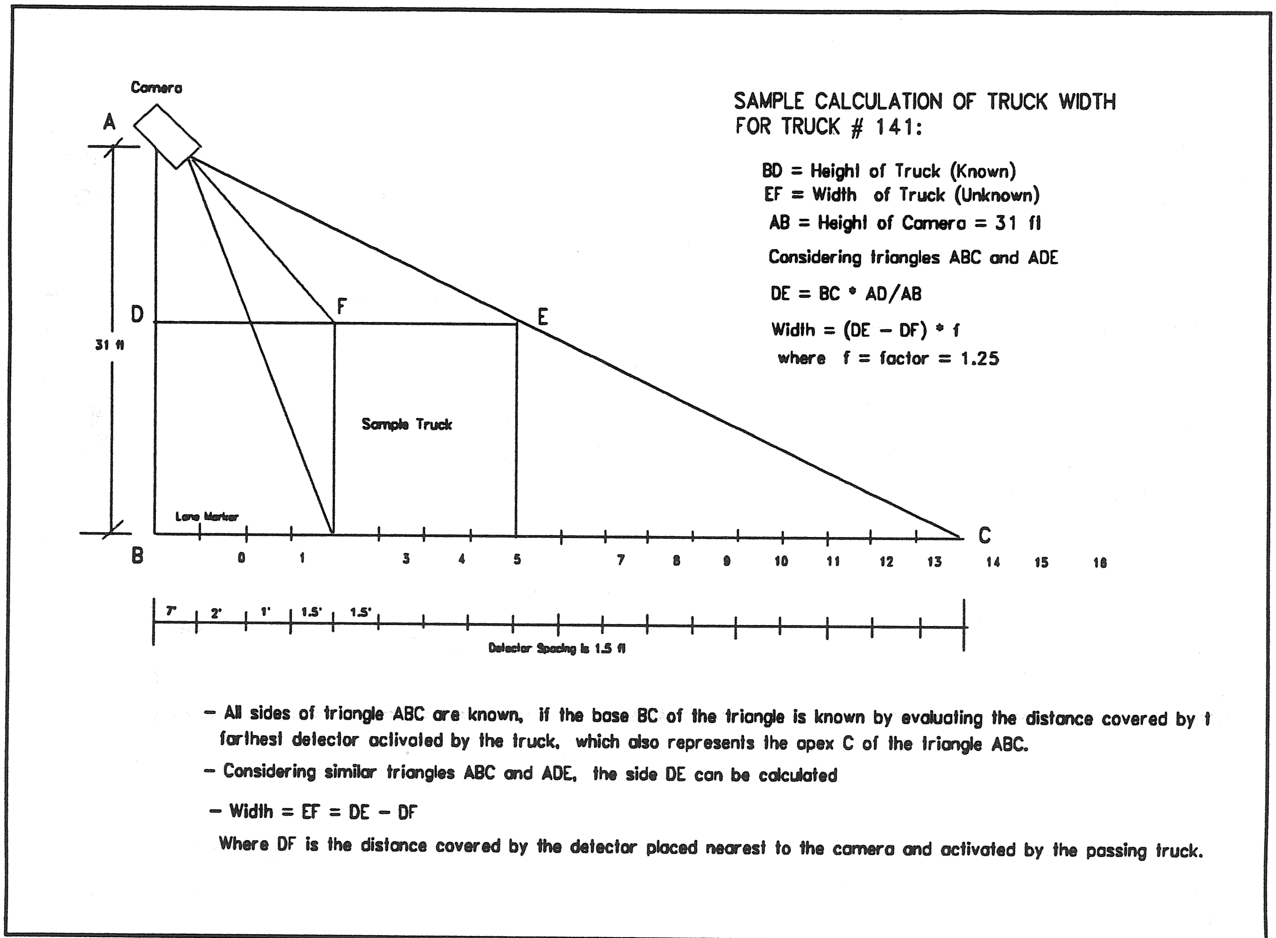

Figure 13. Method of Truck Width Calculation

5.3 Autoscope Data Analysis

Video data recorded for 45 trucks were used to determine the width of the trucks. The distance from the camera to the lane marker of the truck travel lane was seven feet. The camera height above ground was 31 feet. The method of similar triangles was used to estimate the truck width. Detectors were placed on the reference markers established across the width of the lane at 2 feet spacing. When the truck passed by it activated patterns of detectors depending upon its height and width. The width is calculated based on the actual height of the truck measured on site. The results shown are corrected for incorrect detector activations. A geometric correction factor of 1.25 was applied in the width calculation.

The errors are in terms of both overestimation and underestimation of truck widths. The most important factor is the correct activation of detectors which define the two edges of the truck. If one of these detectors is not true then the estimated width is not accurate. The detector nearer to the camera position which is usually activated by the truck tire represents the true inner edge of the truck. Whereas the outer edge of truck defined by the farthest activated detector from camera is not true but has to be accounted for by the geometry. As shown in the Figure 13 this is done by using the method of similar triangles. Most of the time the error was due detector detecting the outer truck edge. Other objects protruding out from the truck such as the exhaust pipe and load on the trailer activated the outer detector. Some times the inner detector was also not activated. This could be due to a lack of color difference between the tire and pavement surface against which the detector was placed.

The Autoscope data output consisting of the number of detector, time of activation, and the duration of activation was used to create the truck width plots shown Figures 14 and 15. Truck width plots for all the 45 trucks are given in the appendix.

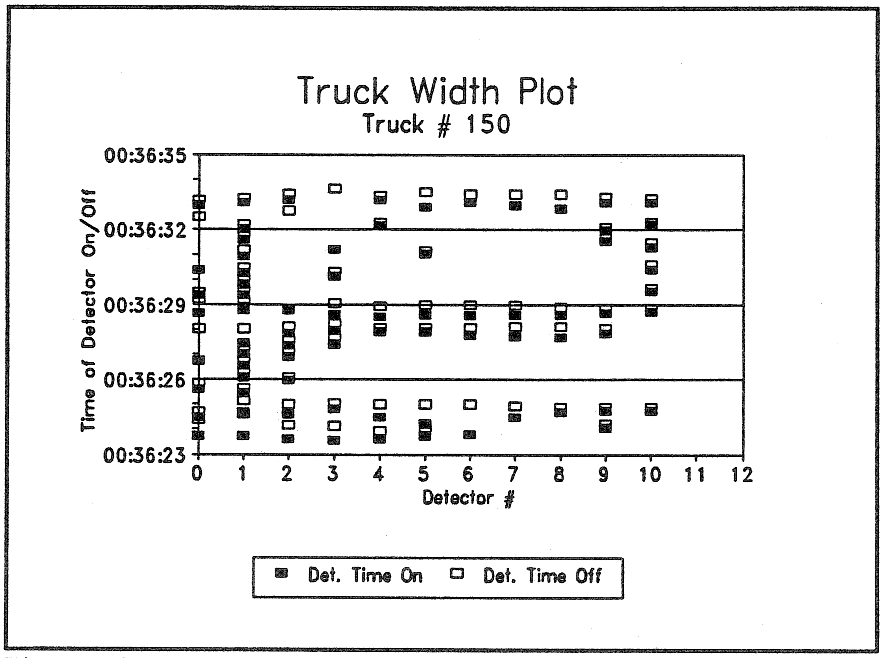

Figure 14

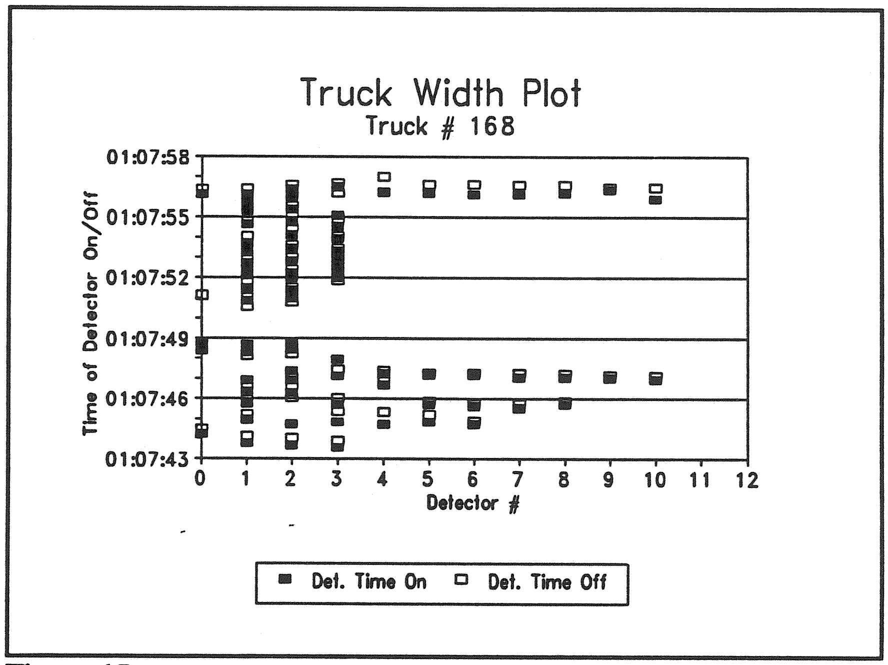

Figure 15

5.4 Width Estimates

The actual and computed widths, as well as the percent errors, are given in Tables 8 and 9. Most of the width estimates were made with errors of ten percent or less.

Table 8. Truck Widths

Truck #	A. Width	C. Width	% Error
141	8.00	7.80	2.47
142	7.83	8.11	-3.53
143	8.00	8.41	-5.17
144	8.00	7.92	1.04
145	7.83	7.54	3.70
146	8.00	8.86	-10.80
147	7.92	8.77	-10.78
148	8.00	7.16	10.45
149	7.92	3.81	51.87
150	8.00	8.88	-11.06
151	8.00	8.61	-7.67
152	8.00	7.63	4.65
153	8.00	8.79	-9.88
154	8.00	7.54	5.75
155	8.00	7.68	3.98
156	8.00	7.54	5.75
157	8.50	8.32	2.16
158	8.00	10.92	-36.49
159	8.00	7.64	4.55
160	8.17	8.61	-5.48
161	8.50	8.61	-1.34
162	8.00	8.13	-1.65

Table 9. Truck Widths

Truck #	A. Width	C. Width	% Error
163	8.00	7.73	3.39
164	8.50	8.77	-3.18
165	8.00	7.92	1.04
166	8.50	8.88	-4.52
167	8.00	7.40	7.51
168	8.50	8.70	-2.31
169	8.50	7.72	9.21
170	8.50	8.71	-2.51
171	8.00	8.42	-5.22
172	7.83	7.04	10.18
173	8.50	8.88	-4.52
174	8.00	8.60	-7.53
175	8.50	8.16	3.98
176	6.50	6.40	1.57
177	7.92	7.58	4.29
178	8.00	8.43	-5.32
179	11.67	10.42	10.71
180	8.00	9.26	-15.76
181	8.00	7.46	6.69
182	7.50	6.18	17.65
183	8.00	8.49	-6.14
184	8.00	7.87	1.59
185	8.00	7.64	4.55
186	8.00	6.37	20.32

5.5 Statistical Tests

A paired t-test was performed to evaluate the difference between the measured and the computed truck widths. These data are given in Table 10.

Table 10. Statistical Analysis of Truck Width Data

Statistic	Measured	Autoscope	Difference
Mean	8.12	8.05	0.070813
Standard Deviation.	0.62	1.08	0.96441
Variance	0.38	1.17	0.948466
Minimum	6.5	3.81	-2.91902
Maximum	11.67	10.92	4.106183

Paired t-test:

H_o: Difference in Means = 0
H_a: Difference in Means is not equal to 0
T.S: t = 0.4926
For a p-value of 0.05, and n=45, t_{table} = 2.01575

Since the t-computed is less than the t-table, the null hypothesis cannot be rejected. Thus it can be concluded that there is no difference between the measured and Autoscope computed widths of trucks.

5.6 Summary/Conclusions

Figure 16 shows the statistical summary of results in terms of frequency with corresponding range of estimated widths. Most of the errors are within 10 percent but some estimations are larger. It is possible to increase accuracy by decreasing the spacing between the detectors and by increasing detector sensitivity to detect slight color differences with respect to the background color. The geometric adjustment factor of 1.25 used cannot be explained accurately, but it might depend on the distance and angle at which the object is located in the camera field of view i.e., the farther the object from the camera line of collimation, the smaller it appears. This implies that the distances represented will be smaller relative to the distances near or directly across the line of collimation. But the ideal camera position which gives the most accurate measurements is directly over the center of the lane. Having a camera in this position is practically not possible unless there is a bridge or a traffic signal system over the lane.

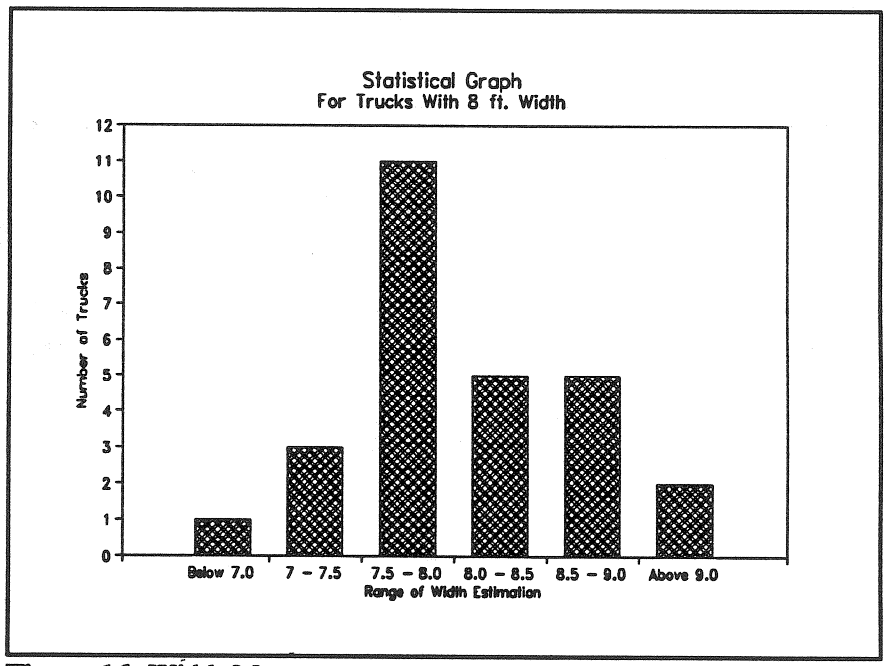

Figure 16. Width Measurements

6. FREEWAY TRAFFIC VOLUME MEASUREMENTS

6.1 Introduction

The purpose of this chapter is to evaluate the efficiency of Autoscope in measuring traffic volumes on freeways for different lighting conditions, camera positions, and for vehicles with side and back shadows. For this purpose video cassettes for seven different camera positions on Boise freeways were analyzed. The seven different scenes are described below along with description of camera location and comments specific to the site.

Analysis of two scenes i.e., for camera positions 1 and 6, was not feasible. Scene 1 is 20 minutes long, and within this time the camera is shaky and shifts positions several times. Thus the analysis of this site using Autoscope is not possible. Scene 6 is one hour long and starts in the early morning hours. It is dark for the first 45 minutes. For this case, the detectors use headlight intensity to detect vehicle passage. The detectors blink on and off or are activated twice for the same vehicle.

Table 11. Freeway Sites

Scene	Duration	Site Description
1	15 min	I84 EB from WB Chinden Exit Ramp Bridge , 3 Lanes, On Coming Traffic
2	20 min	I84 EB from WB Chinden Exit Ramp Bridge, 3 Lanes, Off Going Traffic.
3	27 min	I84 WB from Maple Grove Bridge, 2 Lanes, On Coming Traffic.
4	60 min	I84 WB from Maple Grove Bridge, 3 Lanes (One Merging), Off Going Traffic
5	60 min	I84 WB from Maple Grove Bridge, 3 Lanes (One Merging), Off Going Traffic
6	60 min	I84 EB from Maple Grove Bridge, 2 Lanes, Dark, On Coming Traffic
7	60 min	I84 EB from Maple Grove Bridge, Vehicle , Shadows, Bridge Shadow, 2 Lanes, On Coming Traffic.

6.2 Validation of Autoscope Data

The Autoscope measured volumes are validated using data collected with the TDIP program. The vehicular volumes in each lane are counted using TDIP by pressing keys corresponding to each freeway lane.

(1) The most accurate measurements were made using data from scenes 4 and 5. In these scenes, traffic is moving away from the camera. Autoscope data collected using horizontal video detectors yielded mean absolute percent errors for 5-minute volumes of between 2.4 percent and 7.5 percent for the optimal detector configuration. Overall percent errors ranged from 0.6 percent to 7.1 percent.

(2) Measurements from scene 2, in which traffic was also moving away from the camera, were also reasonably accurate when horizontal video detectors were used. For two lanes, the optimal detector configurations yielded mean absolute percent errors of 9.0 to 11.8 percent for the 5-minute data and overall percent errors from 1.7 to 9.3 percent for horizontal detectors. In the third lane, only vertical detectors were tested. Here, error rates increased substantially: 24.5 percent, mean absolute percent error and 24.1 percent overall error.

(3) Scene 3 was the only case studied for traffic moving toward the camera. Results were mixed. In one lane, the mean absolute percent error for the 5-minute data was 5.2 percent, while in the other lane it was 15.9 percent for the optimal detector settings.

(4) During the initial portion of scene 7, it was dark. In addition, an accident caused very congested traffic movements. The results are variable with mean absolute percent errors range from 13.2 to 18.9 percent for the 2 lanes studied. These challenging conditions should be studied further since the good performance of Autoscope during low light periods and during congested flow periods is a requirement of a traffic control and management system.

Table 12. Freeway Data Summary

SCENE	LANE	DET #	(1)	(2)	OVERALL % ERROR	VOLUMES		(3)
						AUTOSCOPE	TDIP	
2	1	3	H	9.0	-1.7	177	174	75.0
	2	5	H	11.8	-9.3	177	162	75.0
	3	10	V	24.5	24.1	132	174	25.0
3	1	1	H	15.9	13.1	179	206	50.0
	2	8	H	5.2	5.2	218	230	83.3
4	1	0	H	2.4	0.6	820	825	92.9
	2	4	H	4.2	1.6	424	431	83.3
	3	8	H	7.5	7.1	872	939	83.3
5	1	0	H	2.7	1.4	1306	1325	100.0
	2	6	H	6.3	4.8	399	419	100.0
	3	9	H	5.1	5.2	1542	1627	91.7
7	1	2	H	18.9	-11.2	1070	962	66.7
	2	4	H	13.2	-1.8	1370	1346	58.3

(1) Orientation of detector, either horizontal (H) or vertical (V).

(2) Mean absolute percent error for the 5-minute flow data.

(3) Percent of time that the 5-minute error is less than 10 percent.

6.3 Traffic Scene 2

Traffic Scene 2 is 20 minutes in length. It was taped on I84 EB from WB Chinden Exit Ramp Bridge. There are 3 lanes of traffic traveling away from the camera. The lane configuration and video detector layout is shown in Figure 12.

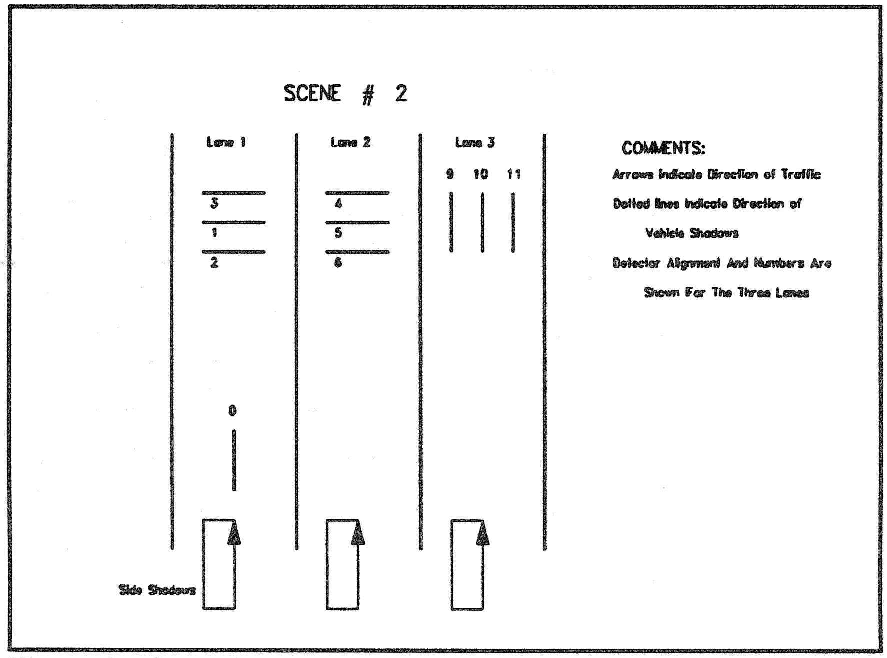

Figure 17. Scene 2

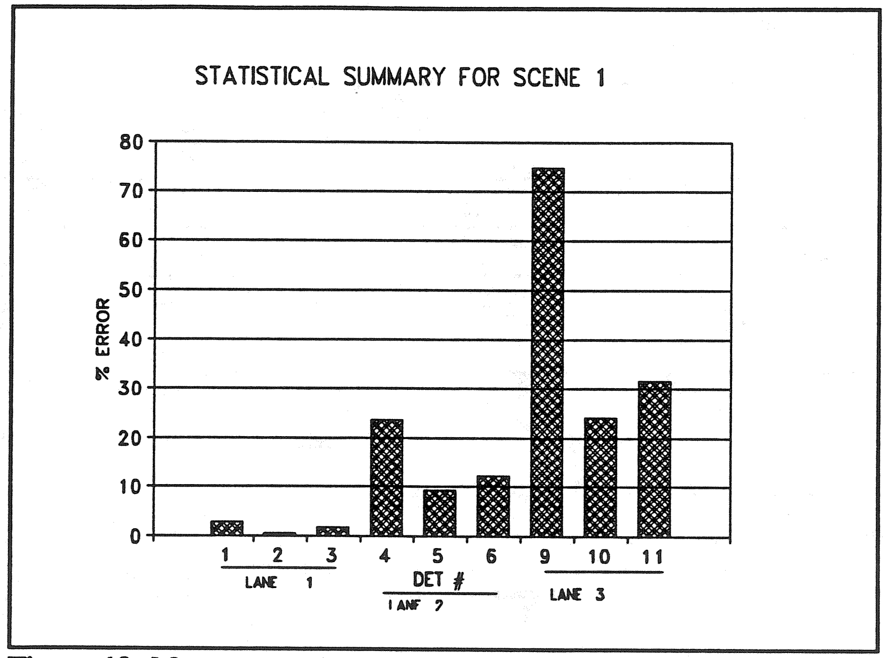

Figure 18. Measurement Errors for Scene 2

Table 13. Scene 2, Lane 1

5 Minute Volumes	TDIP Volumes	Autoscope Volumes					
		Det # 1	% Error	Det # 2	% Error	Det # 3	% Error
12:00:00	49	45	8.2%	46	6.1%	47	4.1%
12:05:00	43	48	-11.6%	46	-7.0%	46	-7.0%
12:10:00	44	41	6.8%	39	11.4%	40	9.1%
12:15:00	38	45	-18.4%	44	-15.8%	44	-15.8%
15 Minute Volumes							
12:00:00	136	134	1.5%	131	3.7%	133	2.2%
12:15:00	38	45	-18.4%	44	-15.8%	44	-15.8%
Total:	174	179	-2.9%	175	-0.6%	177	-1.7%

Table 14. Scene 2, Lane 1

DETECTOR #	PERCENT ERROR	COMMENTS
0	-10.9	Vertical Alignment, Side Shadow Effect
1	-2.9	Horizontal Alignment, Good Results
2	-0.6	Horizontal Alignment, Good Results
3	-1.7	Horizontal Alignment, Good Results

Table 15. Scene 2, Lane 2

5 Minute Volumes	TDIP Volumes	Det # 4	% Error	Det # 5	% Error	Det # 6	% Error
12:00:00	48	62	-29.2%	49	-2.1%	50	-4.2%
12:05:00	36	55	-52.8%	48	-33.3%	52	-44.4%
12:10:00	47	46	2.1%	46	2.1%	45	4.3%
12:15:00	31	37	-19.4%	34	-9.7%	35	-12.9%
15 Minute Volumes							
12:00:00	131	163	-24.4%	143	-9.2%	147	-12.2%
12:15:00	31	37	-19.4%	34	-9.7%	35	-12.9%
Total:	162	200	-23.5%	177	-9.3%	182	-12.3%

Table 16. Scene 2, Lane 2

DETECTOR #	PERCENT ERROR	COMMENTS
4	-23.5	Horizontal Alignment, Effect of Vehicle Color and Changing Lanes Prevalent
5	-9.3	Horizontal Alignment, Same as Above
6	-12.3	Horizontal Alignment, Same as Above

Table 17. Scene 2, Lane 3

5 Minute Volumes	TDIP Volumes	Det # 9	% Error	Det # 10	% Error	Det # 11	% Error
12:00:00	34	13	61.8%	33	2.9%	28	17.6%
12:05:00	31	10	67.7%	36	-16.1%	33	-6.5%
12:10:00	47	9	80.9%	38	19.1%	35	25.5%
12:15:00	62	12	80.6%	25	59.7%	23	62.9%
15 Minute Volumes							
12:00:00	112	32	71.4%	107	4.5%	96	14.3%
12:15:00	62	12	80.6%	25	59.7%	23	62.9%
Total:	174	44	74.7%	132	24.1%	119	31.6%

Table 18. Scene 2, Lane 3

DETECTOR #	PERCENT ERROR	COMMENTS
9	74.7	Vertical Alignment, Most of the Vehicles Miss the Corner Detectors, i.e., Det # 9 and 11 in this Lane.
10	24.1	Vertical Alignment, Best Among all the Detectors in this Lane, but still Many vehicles Miss this Detector Undetected. Horizontal Detectors will be More Accurate
11	31.6	Vertical Alignment, Reason same as explained for Detector 9

6.4 Traffic Scene 3

Traffic scene 3 is 27 minutes in length. The videotape was taken of I84 WB from the Maple Grove Bridge. The scene includes 2 lanes, with traffic coming towards the camera.

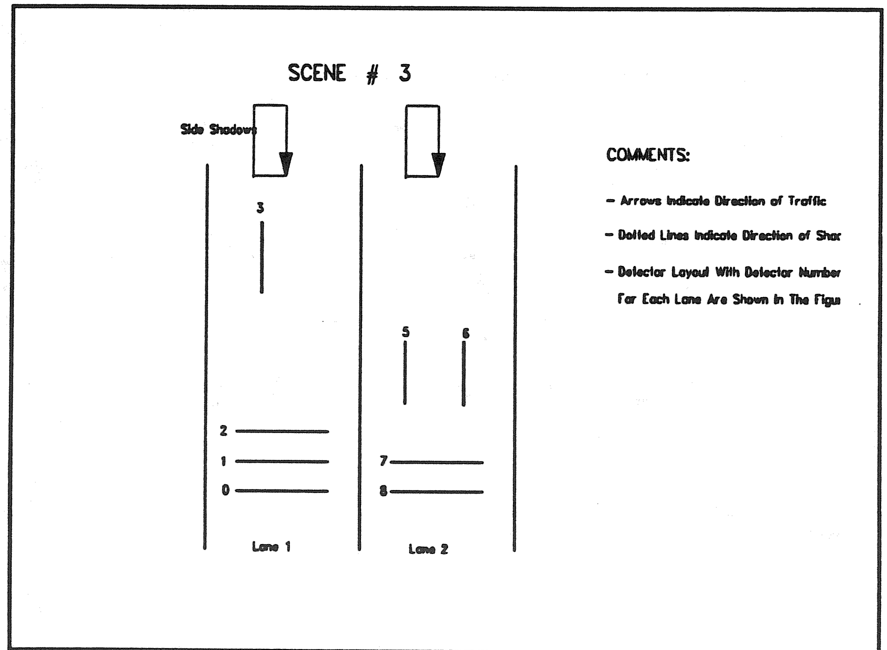

Figure 19

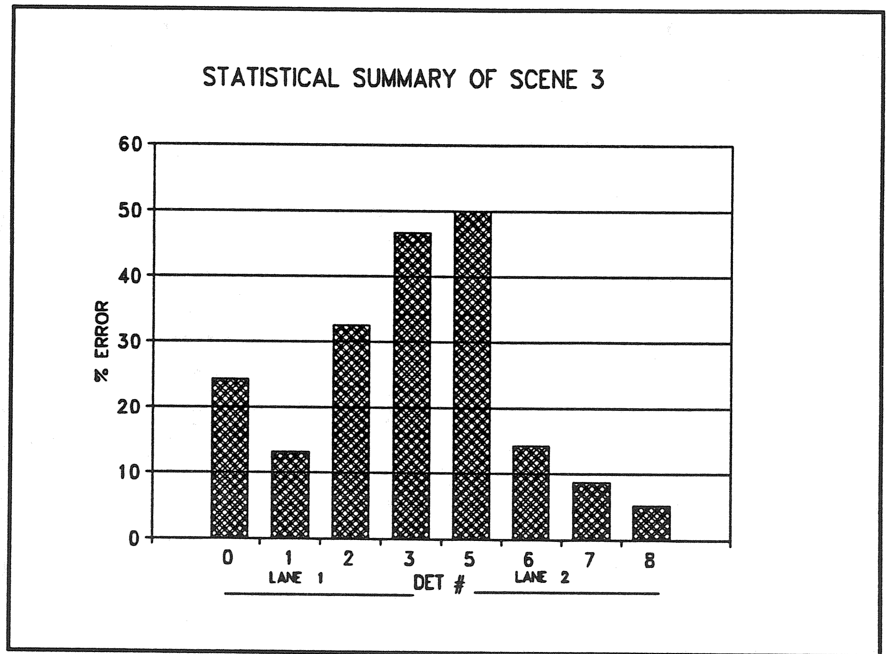
STATISTICAL SUMMARY OF SCENE 3
% ERROR
60
50
40
30
20
10
0
0
1
2
3
5
6
7
8
LANE 1
DET #
LANE 2

Figure 20

Table 19. Scene 3, Lanes 1 and 2

LANE 1:									
5 Minute Volumes	TDIP Volumes	Autoscope Volumes							
		Det # 0	% Error	Det # 1	% Error	Det # 2	% Error	Det # 3	% Error
12:00:00	33	33	0.0%	30	9.1%	18	45.5%	12	63.6%
12:05:00	50	35	30.0%	39	22.0%	33	34.0%	25	50.0%
12:10:00	38	20	47.4%	24	36.8%	16	57.9%	14	63.2%
12:15:00	36	30	16.7%	33	8.3%	27	25.0%	26	27.8%
12:20:00	30	23	23.3%	31	-3.3%	27	10.0%	20	33.3%
12:25:00	19	15	21.1%	22	-15.8%	18	5.3%	13	31.6%
15 Minute Volumes									
12:00:00	121	88	27.3%	93	23.1%	67	44.6%	51	57.9%
12:15:00	85	68	20.0%	86	-1.2%	72	15.3%	59	30.6%
Total:	206	156	24.3%	179	13.1%	139	32.5%	110	46.6%
LANE 2:									
5 Minute Volumes	TDIP Volumes	Det # 5	% Error	Det # 6	% Error	Det # 7	% Error	Det # 8	% Error
12:00:00	36	21	41.7%	31	13.9%	31	13.9%	34	5.6%
12:05:00	43	20	53.5%	36	16.3%	39	9.3%	43	0.0%
12:10:00	28	17	39.3%	22	21.4%	25	10.7%	24	14.3%
12:15:00	55	20	63.6%	45	18.2%	47	14.5%	50	9.1%
12:20:00	48	22	54.2%	46	4.2%	47	2.1%	47	2.1%
12:25:00	20	15	25.0%	17	15.0%	21	-5.0%	20	0.0%
15 Minute Volumes									
12:00:00	107	58	45.8%	89	16.8%	95	11.2%	101	5.6%
12:15:00	123	57	53.7%	108	12.2%	115	6.5%	117	4.9%
Total:	230	115	50.0%	197	14.3%	210	8.7%	218	5.2%

Table 20. Scene 3, Lane 1

DETECTOR #	PERCENT ERROR	COMMENTS
0	24.3	Horizontal Alignment, Effect of Dark Colored Vehicles is Very Widespread, Fast Moving Vehicles are Not detected, Still there is No Clear Cut Reason for this Type of Detector Behavior.
1	13.1	Horizontal Alignment, Same as Above
2	32.5	Horizontal Alignment, Same as Above
3	46.6	Vertical Alignment, Most of the Vehicles Miss this Detector

Table 21. Scene 3, Lane 2

DETECTOR #	PERCENT ERROR	COMMENTS
5	50.0	Vertical Alignment, Most of the vehicles miss this detector
6	14.3	Same as above
7	8.7	Results are o.k., Effect of color of vehicles
8	5.2	Good Results

6.5 Traffic Scene 4

Traffic scene 4 is 60 minutes in length. It was videotaped along I84 WB from the Maple Grove Bridge. The scene included 3 lanes of traffic including one merging lane, with traffic traveling away from the camera.

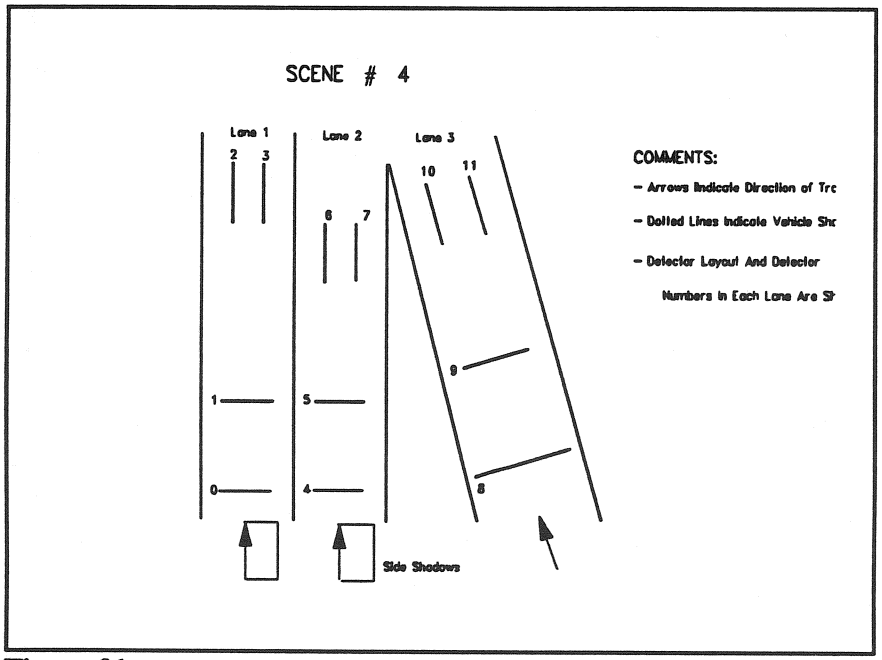

Figure 21

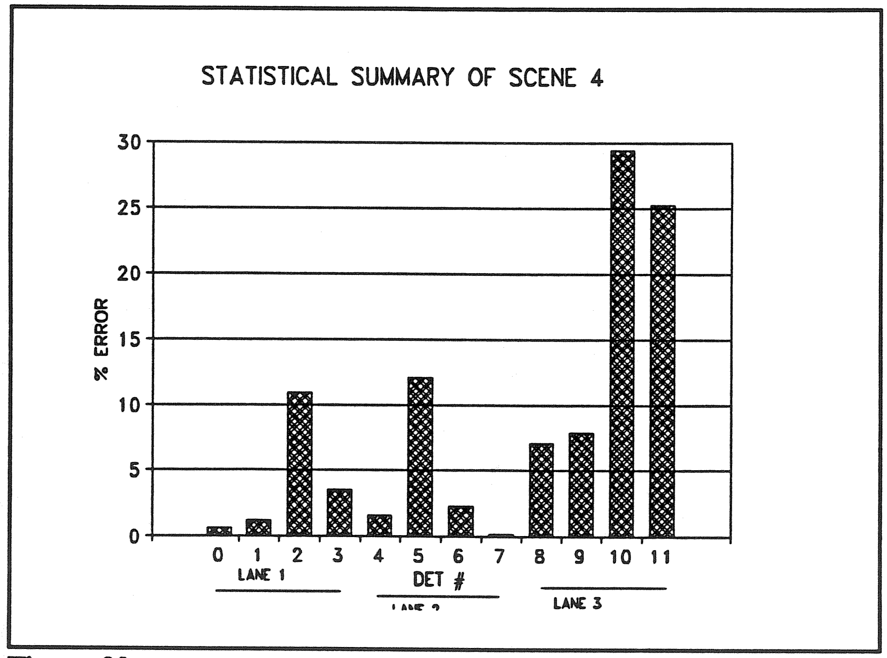
STATISTICAL SUMMARY OF SCENE 4
% ERROR
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11
DET #
LANE 1
LANE 3

Figure 22

Table 22. Scene 4, Lane 1

5 Minute Volumes	TDIP Volumes	AUTOSCOPE VOLUMES							
		Det # 0	% Error	Det # 1	% Error	Det # 2	% Error	Det # 3	% Error
12:00:00	39	39	0.0%	32	17.9%	31	20.5%	34	12.8%
12:05:00	70	73	-4.3%	76	-8.6%	63	10.0%	55	21.4%
12:10:00	88	87	1.1%	91	-3.4%	75	14.8%	83	5.7%
12:15:00	82	79	3.7%	81	1.2%	69	15.9%	81	1.2%
12:20:00	61	60	1.6%	60	1.6%	56	8.2%	60	1.6%
12:25:00	64	61	4.7%	66	-3.1%	59	7.8%	67	-4.7%
12:30:00	54	55	-1.9%	57	-5.6%	49	9.3%	57	-5.6%
12:35:00	76	72	5.3%	74	2.6%	64	15.8%	71	6.6%
12:40:00	88	90	-2.3%	91	-3.4%	84	4.5%	91	-3.4%
12:45:00	74	75	-1.4%	77	-4.1%	65	12.2%	72	2.7%
12:50:00	68	67	1.5%	67	1.5%	63	7.4%	63	7.4%
12:55:00	61	62	-1.6%	63	-3.3%	57	6.6%	62	-1.6%
12:00:00	197	199	-1.0%	199	-1.0%	169	14.2%	172	12.7%
12:15:00	207	200	3.4%	207	0.0%	184	11.1%	208	-0.5%
15 Min Volume									
12:30:00	218	217	0.5%	222	-1.8%	197	9.6%	219	-0.5%
12:45:00	203	204	-0.5%	207	-2.0%	185	8.9%	197	3.0%
Total:	825	820	0.6%	835	-1.2%	735	10.9%	796	3.5%

Table 23. Scene 4, Lane 1

DETECTOR #	PERCENT ERROR	COMMENTS
0	0.6	Good Results
1	-1.2	Good Results
2	10.9	Vertical Alignment, most vehicles miss this detector as compared to Det # 3
3	3.5	Good Results, Vertical Det. Alignment

Table 24. Scene 4, Lane 2

5 Minute Volumes	TDIP Volumes	Det # 4	% Error	Det # 5	% Error	Det # 6	% Error	Det # 7	% Error
12:00:00	35	32	8.6%	33	5.7%	34	2.9%	27	22.9%
12:05:00	35	31	11.4%	21	40.0%	25	28.6%	29	17.1%
12:10:00	44	44	0.0%	32	27.3%	46	-4.5%	46	-4.5%
12:15:00	45	44	2.2%	39	13.3%	44	2.2%	37	17.8%
12:20:00	37	37	0.0%	30	18.9%	42	-13.5%	38	-2.7%
12:25:00	37	37	0.0%	34	8.1%	40	-8.1%	42	-13.5%
12:30:00	35	37	-5.7%	33	5.7%	35	0.0%	38	-8.6%
12:35:00	34	34	0.0%	30	11.8%	32	5.9%	34	0.0%
12:40:00	41	39	4.9%	36	12.2%	36	12.2%	41	0.0%
12:45:00	28	27	3.6%	27	3.6%	30	-7.1%	34	-21.4%
12:50:00	31	30	3.2%	33	-6.5%	41	-32.3%	28	9.7%
12:55:00	29	32	-10.3%	31	-6.9%	36	-24.1%	36	-24.1%
15 Minute Volumes	TDIP Volume	Det # 4	% Err	Det # 5	% Err	Det # 6	% Err	Det # 7	% Err
12:00:00	114	107	6.1%	86	24.6%	105	7.9%	102	10.5%
12:15:00	119	118	0.8%	103	13.4%	126	-5.9%	117	1.7%
12:30:00	110	110	0.0%	99	10.0%	103	6.4%	113	-2.7%
12:45:00	88	89	-1.1%	91	-3.4%	107	-21.6%	98	-11.4%
Total:	431	424	1.6%	379	12.1%	441	-2.3%	430	0.2%

Table 25. Scene 4, Lane 2

DETECTOR #	PERCENT ERROR	COMMENTS
4	1.6	Good Results
5	12.1	No definite reason, vehicles changing lanes might be one of the reasons
6	-2.3	Good Results, Vertical Alignment
7	0.2	Good Results, Vertical Alignment

Table 26. Scene 4, Lane 3

5 Minute Volumes	TDIP Volumes	Det # 8	% Error	Det # 9	% Error	Det # 10	% Error	Det # 11	% Error
12:00:00	65	47	27.7%	50	23.1%	46	29.2%	33	49.2%
12:05:00	79	76	3.8%	67	15.2%	67	15.2%	60	24.1%
12:10:00	88	85	3.4%	84	4.5%	65	26.1%	66	25.0%
12:15:00	75	70	6.7%	71	5.3%	51	32.0%	58	22.7%
12:20:00	74	70	5.4%	70	5.4%	60	18.9%	57	23.0%
12:25:00	66	63	4.5%	63	4.5%	49	25.8%	54	18.2%
12:30:00	81	70	13.6%	73	9.9%	51	37.0%	59	27.2%
12:35:00	80	79	1.3%	74	7.5%	55	31.3%	62	22.5%
12:40:00	86	84	2.3%	81	5.8%	57	33.7%	67	22.1%
12:45:00	77	72	6.5%	72	6.5%	44	42.9%	55	28.6%
12:50:00	87	82	5.7%	84	3.4%	66	24.1%	75	13.8%
12:55:00	81	74	8.6%	76	6.2%	52	35.8%	56	30.9%
15 Minute Volumes									
12:00:00	232	208	10.3%	201	13.4%	178	23.3%	159	31.5%
12:15:00	215	203	5.6%	204	5.1%	160	25.6%	169	21.4%
12:30:00	247	233	5.7%	228	7.7%	163	34.0%	188	23.9%
12:45:00	245	228	6.9%	232	5.3%	162	33.9%	186	24.1%
Total:	939	872	7.1%	865	7.9%	663	29.4%	702	25.2%

Table 27. Scene 4, Lane 3

DETECTOR #	PERCENT ERROR	COMMENTS
8	7.1	Effect of color of vehicles, significant number of vehicles change lanes before passing through detector zone
9	7.9	Same as Above
10	29.4	Vertical Alignment, Most Vehicles miss the detector
11	25.2	Same as Above

6.6 Traffic Scene 5

Traffic scene 5 is 60 minutes in length. The videotape was taken from I84 WB at the Maple Grove Bridge. The scene includes 3 lanes of traffic, including one merging lane. Traffic is traveling away from the camera.

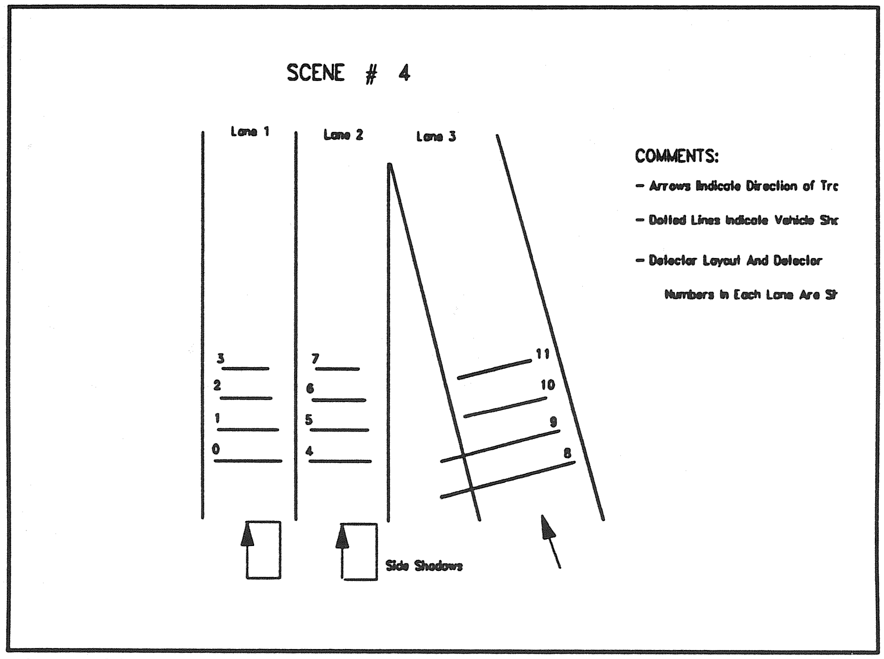

Figure 23

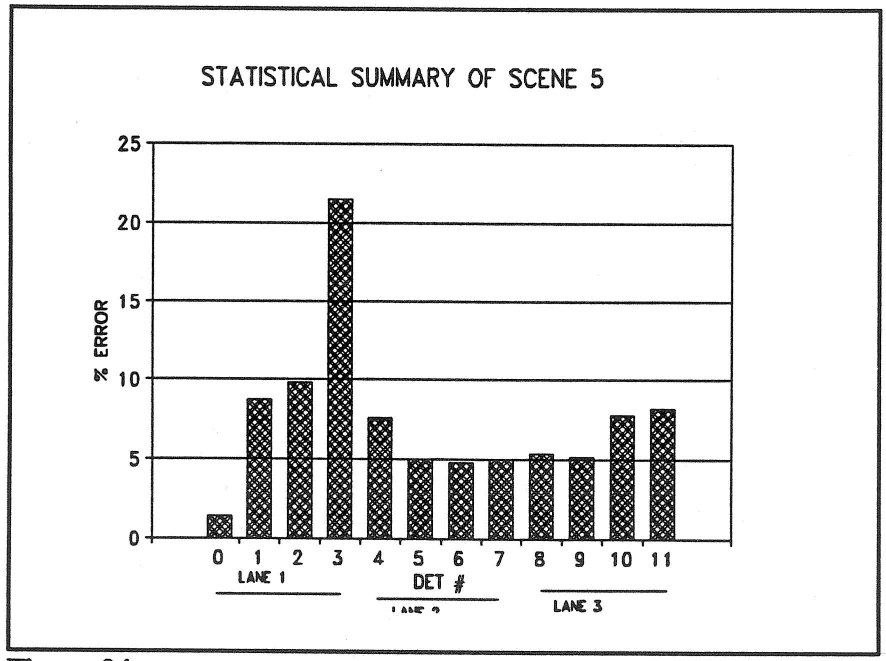
STATISTICAL SUMMARY OF SCENE 5
% ERROR
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11
LANE 1
DET #
LANE 3

Figure 24

Table 28. Scene 5, Lane 1

5 Minute Volumes	TDIP Volumes	Autoscope Volumes							
		Det # 0	% Error	Det # 1	% Error	Det # 2	% Error	Det # 3	% Error
12:00:00	99	96	3.0%	89	10.1%	85	14.1%	76	23.2%
12:05:00	126	126	0.0%	114	9.5%	117	7.1%	97	23.0%
12:10:00	112	107	4.5%	93	17.0%	96	14.3%	87	22.3%
12:15:00	93	92	1.1%	85	8.6%	84	9.7%	72	22.6%
12:20:00	83	78	6.0%	79	4.8%	73	12.0%	65	21.7%
12:25:00	89	88	1.1%	83	6.7%	83	6.7%	71	20.2%
12:30:00	125	127	-1.6%	119	4.8%	120	4.0%	96	23.2%
12:35:00	125	119	4.8%	111	11.2%	115	8.0%	106	15.2%
12:40:00	150	155	-3.3%	136	9.3%	136	9.3%	116	22.7%
12:45:00	116	117	-0.9%	110	5.2%	101	12.9%	93	19.8%
12:50:00	119	118	0.8%	107	10.1%	103	13.4%	90	24.4%
12:55:00	88	83	5.7%	84	4.5%	82	6.8%	71	19.3%
15 Minute	Volume								
12:00:00	337	329	2.4%	296	12.2%	298	11.6%	260	22.8%
12:15:00	265	258	2.6%	247	6.8%	240	9.4%	208	21.5%
12:30:00	400	401	-0.3%	366	8.5%	371	7.3%	318	20.5%
12:45:00	323	318	1.5%	301	6.8%	286	11.5%	254	21.4%
Total:	1325	1306	1.4%	1210	8.7%	1195	9.8%	1040	21.5%

Table 29. Scene 5, Lane 1

DETECTOR #	PERCENT ERROR	COMMENTS
0	1.4	Good Results
1	8.7	Effect of Dark colored vehicles
2	9.8	Same as Above
3	21.5	No exact reason for its behavior, may be due to sunlight reflection from pavement surface at that point, Color of Vehicles is more pronounced on this detector as compared to other detectors in the lane.

Table 30. Scene 5, Lane 2

5 Minute Volumes	TDIP Volumes	Det # 4	% Error	Det # 5	% Error	Det # 6	% Error	Det # 7	% Error
12:00:00	41	38	7.3%	39	4.9%	38	7.3%	38	7.3%
12:05:00	36	36	0.0%	33	8.3%	34	5.6%	35	2.8%
12:10:00	41	40	2.4%	41	0.0%	38	7.3%	37	9.8%
12:15:00	31	32	-3.2%	32	-3.2%	33	-6.5%	33	-6.5%
12:20:00	28	23	17.9%	26	7.1%	26	7.1%	26	7.1%
12:25:00	35	33	5.7%	34	2.9%	36	-2.9%	36	-2.9%
12:30:00	35	28	20.0%	30	14.3%	32	8.6%	31	11.4%
12:35:00	36	35	2.8%	33	8.3%	35	2.8%	32	11.1%
12:40:00	38	33	13.2%	38	0.0%	35	7.9%	35	7.9%
12:45:00	30	26	13.3%	26	13.3%	27	10.0%	27	10.0%
12:50:00	30	27	10.0%	29	3.3%	27	10.0%	29	3.3%
12:55:00	38	36	5.3%	37	2.6%	38	0.0%	39	-2.6%
15 Minute Volumes	TDIP Volume	Autosc Volume							
		Det # 4	% Err	Det # 5	% Err	Det # 6	% Err	Det # 7	% Err
12:00:00	118	114	3.4%	113	4.2%	110	6.8%	110	6.8%
12:15:00	94	88	6.4%	92	2.1%	95	-1.1%	95	-1.1%
12:30:00	109	96	11.9%	101	7.3%	102	6.4%	98	10.1%
12:45:00	98	89	9.2%	92	6.1%	92	6.1%	95	3.1%
Total:	419	387	7.6%	398	5.0%	399	4.8%	398	5.0%

Table 31. Scene 5, Lane 2

DETECTOR #	PERCENT ERROR	COMMENTS
4	7.6	The average error for all detectors in this lane is 5% below TDIP values, there is no other reason except for effect of dark colored vehicles.
5	5.0	Same as Above
6	4.8	Same as Above
7	5.0	Same as Above

Table 32. Scene 5, Lane 3

5 Minute Volumes	TDIP Volumes	Det # 8	% Error	Det # 9	% Error	Det # 10	% Error	Det # 11	% Error
12:00:00	120	114	5.0%	118	1.7%	114	5.0%	114	5.0%
12:05:00	120	116	3.3%	118	1.7%	118	1.7%	117	2.5%
12:10:00	133	131	1.5%	130	2.3%	128	3.8%	127	4.5%
12:15:00	126	122	3.2%	121	4.0%	120	4.8%	118	6.3%
12:20:00	111	102	8.1%	104	6.3%	101	9.0%	100	9.9%
12:25:00	145	120	17.2%	115	20.7%	114	21.4%	114	21.4%
12:30:00	140	133	5.0%	135	3.6%	131	6.4%	129	7.9%
12:35:00	169	164	3.0%	163	3.6%	153	9.5%	152	10.1%
12:40:00	142	132	7.0%	136	4.2%	132	7.0%	134	5.6%
12:45:00	166	157	5.4%	157	5.4%	150	9.6%	154	7.2%
12:50:00	137	131	4.4%	131	4.4%	128	6.6%	128	6.6%
12:55:00	118	117	0.8%	114	3.4%	111	5.9%	107	9.3%
15 Minute Volumes									
12:00:00	373	361	3.2%	366	1.9%	360	3.5%	358	4.0%
12:15:00	382	344	9.9%	340	11.0%	335	12.3%	332	13.1%
12:30:00	451	429	4.9%	434	3.8%	416	7.8%	415	8.0%
12:45:00	421	405	3.8%	402	4.5%	389	7.6%	389	7.6%
Total:	1627	1539	5.4%	1542	5.2%	1500	7.8%	1494	8.2%

Table 33. Scene 5, Lane 3

DETECTOR #	PERCENT ERROR	COMMENTS
8	5.4	Same as Above
9	5.2	Same as Above
10	7.8	Same as Above
11	8.2	Same as Above

6.7 Traffic Scene 7

Traffic scene 7 is 60 minutes in length. It was videotaped along I84 EB from the Maple Grove Bridge. There were both vehicle shadows and bridge shadows in the scene. There were 2 lanes of traffic, coming toward the camera.

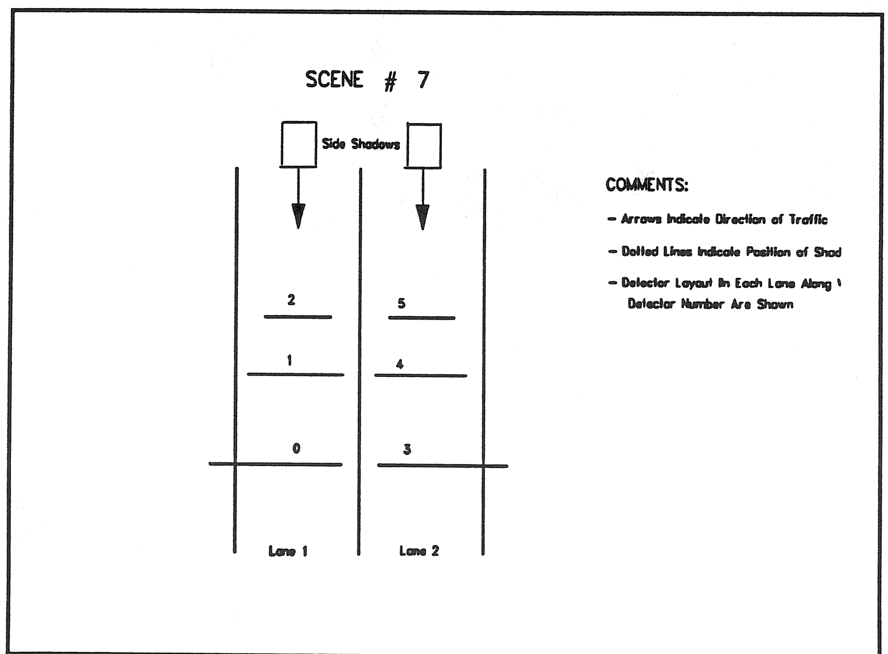

Figure 25

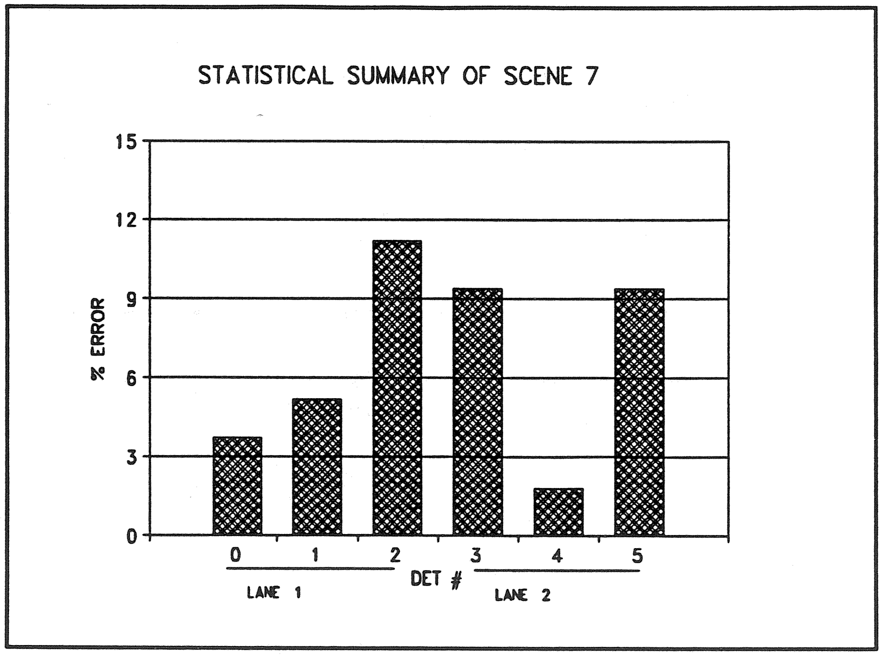
STATISTICAL SUMMARY OF SCENE 7
% ERROR
15
12
9
6
3
0
0
1
2
3
4
5
DET #
LANE 1
LANE 2

Figure 26

Table 34. Scene 7, Lane 1

5 Minute Volumes	TDIP Volumes	AUTOSCOPE VOLUMES					
		Det # 0	% Error	Det # 1	% Error	Det # 2	% Error
12:00:00	88	103	-17.0%	102	-15.9%	109	-23.9%
12:05:00	90	118	-31.1%	126	-40.0%	145	-61.1%
12:10:00	19	7	63.2%	11	42.1%	37	-94.7%
12:15:00	85	84	1.2%	89	-4.7%	88	-3.5%
12:20:00	78	62	20.5%	65	16.7%	83	-6.4%
12:25:00	92	75	18.5%	100	-8.7%	98	-6.5%
12:30:00	104	105	-1.0%	120	-15.4%	116	-11.5%
12:35:00	104	103	1.0%	107	-2.9%	104	0.0%
12:40:00	106	104	1.9%	107	-0.9%	100	5.7%
12:45:00	80	80	0.0%	87	-8.8%	81	-1.3%
12:50:00	62	48	22.6%	53	14.5%	60	3.2%
12:55:00	54	37	31.5%	45	16.7%	49	9.3%
15 Minute	Volume						
12:00:00	197	228	-15.7%	239	-21.3%	291	-47.7%
12:15:00	255	221	13.3%	254	0.4%	269	-5.5%
12:30:00	314	312	0.6%	334	-6.4%	320	-1.9%
12:45:00	196	165	15.8%	185	5.6%	190	3.1%
Total:	962	926	3.7%	1012	-5.2%	1070	-11.2%

Table 35. Scene 7, Lane 2

5 Minute Volumes	TDIP Volumes	Det # 3	% Error	Det # 4	% Error	Det # 5	% Error
12:00:00	103	127	-23.3%	134	-30.1%	148	-43.7%
12:05:00	102	136	-33.3%	132	-29.4%	159	-55.9%
12:10:00	103	129	-25.2%	113	-9.7%	104	-1.0%
12:15:00	126	126	0.0%	129	-2.4%	130	-3.2%
12:20:00	120	71	40.8%	103	14.2%	134	-11.7%
12:25:00	109	48	56.0%	103	5.5%	116	-6.4%
12:30:00	124	118	4.8%	131	-5.6%	125	-0.8%
12:35:00	123	120	2.4%	135	-9.8%	133	-8.1%
12:40:00	143	141	1.4%	142	0.7%	148	-3.5%
12:45:00	131	106	19.1%	126	3.8%	131	0.0%
12:50:00	102	57	44.1%	74	27.5%	89	12.7%
12:55:00	60	41	31.7%	48	20.0%	55	8.3%
15 Minute Volumes	TDIP Volume	Autoscope Volume					
		Det # 3	% Err	Det # 4	% Err	Det # 5	% Err
12:00:00	308	392	-27.3%	379	-23.1%	411	-33.4%
12:15:00	355	245	31.0%	335	5.6%	380	-7.0%
12:30:00	390	379	2.8%	408	-4.6%	406	-4.1%
12:45:00	293	204	30.4%	248	15.4%	275	6.1%
Total:	1346	1220	9.4%	1370	-1.8%	1472	-9.4%

Table 36. Scene 7, Lane 1

DETECTOR #	PERCENT ERROR	COMMENTS
0	3.7	Good Results, the beginning part of this scene is dark and effect of accident in lane 1 occurs in the first of the tape, which makes vehicles in lane 1 to change lane 2 or pass through the shoulder to avoid the accident site. The other problem is poor lighting conditions during the beginning part of the tape, therefore the effect of reflection of wind screen of vehicles is also prevalent along with the effect of vehicles changing lanes in the first part of the tape, after this initial disturbance, the conditions are good (i.e., lighting conditions are improving with time, and accident site is cleared) the detectors are very accurate in measuring the traffic flow rates, therefore the results given are a average for both the bad and good conditions.
1	-5.2	Same as Above
2	-11.2	Same as Above

Table 37, Scene 7, Lane 2

DETECTOR #	PERCENT ERROR	COMMENTS
3	9.4	Same as for Lane 1
4	-1.8	Same as Above
5	-9.4	Same as Above

6.8 Summary/Conclusions

Freeway traffic volume counts measured by Autoscope are accurate for most of the lanes in the different scenes studied here. The major errors are due to the alignment of the detectors, the color of vehicles, and effect of shadows. Note that the effect of shadows has been effectively reduced using the shadow algorithm available in the Autoscope system. The vertical detectors are more sensitive in identifying vehicles. But since they cannot be placed over wide areas on the lane many vehicles miss these detectors resulting in underestimation of traffic volumes. This problem can be eliminated by using only horizontally aligned detectors. The results also indicate the same pattern i.e., results of horizontal detectors are more accurate as compared to vertical detectors.

7. SUMMARY OF TEST RESULTS

The results of four separate measurement studies are presented here: truck heights, truck lengths, truck widths, and freeway volumes. For each measurement, five elements are included: the objective of the measurement, the method used for the measurement, the major results, an analysis of the results, and recommended actions for the remaining portion of the study.

7.1 Truck Height Measurements

Objective

The objective of the truck height measurement test is to determine how accurately Autoscope can measure the height of trucks passing through a port-of-entry station.

Method

Trucks were videotaped as they were leaving the Lewiston port-of-entry station. A reference grid was established on a utility pole at the port-of-entry directly across from the video camera. The grid was divided into one-foot increments using colored tape placed on the utility pole. The trucks were traveling at approximately five to ten miles per hour as they passed the camera/utility reference pole location. Before leaving the port-of-entry, the maximum height of the truck (either the cab or trailer, but not the exhaust stack or other extrusion) was measured using a standard measurement rod.

The videotape was processed using the Autoscope system. Video detectors were placed on the television monitor at the same locations that the tape markers were placed on the utility pole. This provided a reference grid from which height measurements could be made. As a truck passed through the video detector grid, patterns of detectors were activated according to the shape of the truck. The greater the height of the truck, the larger the number of video detectors activated at a given time.

Results

Visual representation of the truck image. Accurate visual representations of the trucks remarkably similar to the actual shapes of the trucks were produced by constructing time plots of the times that each detector turned on and off.

Estimates of truck height. The pattern of detector on and off times were analyzed for each truck. Truck heights were estimated by multiplying the maximum number of detectors that were on at a given time by the spacing between the detectors.

(1) The estimated truck heights using Autoscope detector data were within 5 percent of the actual heights for 61 percent of the trucks measured and within 10 percent of the actual heights for 86 percent of the trucks measured. Note that this level of accuracy was achieved even within the limitation of the one-foot video detector grid.

(2) Fourteen percent of the measurement errors exceeded 10 percent. About half of these errors (generally underestimates) can be attributed to the apparent difficulty in detecting certain shapes and colors against the background available, particularly silver cylindrical trailers. The other half of these larger measurement errors (generally overestimates) can be attributed to extrusions from the vehicles, such as exhaust pipes, that were not included in the manual measurements.

Analysis and Recommendations

1. The results from this test show that Autoscope offers excellent potential for measuring truck heights.

2. Accurate visual representations of the trucks have been produced using time plots of the detector on-off times.

3. Measurement error was less than 10 percent for 86 percent of the trucks studied.

4. Several recommendations should be considered for improving the accuracy of truck height measurements:

   (a) more closely spaced video detector grids to improve the accuracy of the truck measurements.

   (b) more detailed tests on detector sensitivity for the vehicle shapes and colors that were identified as problems in this initial analysis.

   (c) development of software to automatically process the detector data.

7.2 Truck Length Measurements

Objective

The objective of the truck length measurement test was to determine how accurately Autoscope could measure the length of a truck passing through a port-of-entry system.

Method

Trucks were videotaped as they were leaving the port-of-entry station. A reference grid was established on the travel lane by marking 5 foot increments with colored tape on the pavement. The reference grid extended a distance of 100 feet to the left of the video camera location. Trucks were traveling at approximately 5 to 10 miles per hour as they passed through the measurement grid. Before leaving the POE, axle-to-axle and bumper-to-bumper lengths of each truck were measured and recorded.

The videotape was processed using the Autoscope system. Video detectors were placed on the television monitor at the same locations that the tape markers were placed on the pavement. This provided a reference grid from which length measurements could be made. As the truck passed through the video detector grid, patterns of detectors were activated according to the length of the truck. The greater the number of detectors activated at the same time, the greater the length of the truck. Truck lengths were also estimated based on the travel time between two adjacent detectors and the time during which the detectors were activated.

Results

Truck Progression Method. There is a direct correspondence between the length of the truck and the maximum number of detectors activated at any given time during a truck passage through the detector grid. But because the site geometry conditions were not accurately determined, the actual correspondence between measured length and the estimated length could not be accurately determined with the site geometry data available to estimate length: measurement errors varied from 10 percent to 40 percent.

Truck Speed Method. The speed method also yielded a widely varying error rate for truck length estimates. Several detector combinations yielded error ranges from 10 to 40 percent.

Analysis and Recommendations

The potential for the accurate measurement of truck length has been shown. But an assessment of the measurement results and the field methods used to collect the data show that several changes need to be made to the measurement process to significantly improve the results. The length measurement estimates were extremely sensitive to the geometry of the detector placement. All detectors were placed to the left of the camera, thus exaggerating the effects of any measurement errors. The combination of a wide-angle lens (now available) and the use of detectors on both sides of the camera should reduce the errors induced by this geometry and image offset.

7.3 Truck Width Measurements

Objective

The objective of this test is to determine the accuracy of Autoscope to measure truck widths at a port-of-entry.

Method

Two cameras were used to collect data. One was placed on ground shooting straight across the truck lane and the other was mounted on a Mast raised to a height of 30 feet and located on the side of the lane. The camera mounted on the Mast was used to collect data at two different angles. Video data for the steeper camera angle of inclination was suitable for analysis. All horizontal distances from the camera were recorded, and markers with a colored tape were placed on the pavement at known spacing.

Detector grids were placed by using Autoscope on the reference points marked on the pavement surface. When a truck passed it activated a set or pattern of detectors depending upon its height and width. The activated detectors on the edges define the width of truck. The method of similar triangle was used to determine the actual or true outer truck edge position and the width was computed.

Results

Truck widths for 45 trucks were analyzed, 27 of these had a width of 8 feet. The Autoscope estimated width had an error of 0.5 feet for 16 of these trucks and a error of 1 ft for 8 of the trucks. There were both over estimations and underestimations of truck widths by Autoscope but for most cases the error was less than 10%.

Analysis and Recommendations

It is possible to measure truck widths using the Autoscope system. By increasing the sensitivity of the video detectors and by using a closer spacing of the detectors the accuracy can be significantly increased.

7.4 Freeway Volume Measurements

Objective

The objective of the freeway volume measurement test was to determine how accurately Autoscope could measure volume or flow rates along a freeway for a variety of lighting, shadow, flow direction, and detector placement conditions.

Method

Traffic was videotaped from several overpass locations along I-184 in Boise. Various detector patterns were studied, including horizontal detectors (perpendicular to the traffic flow) and vertical detectors (parallel to the traffic flow). The videotape was processed using the Autoscope system, producing 5-minute and 15-minute volume counts. As a check, the Traffic Data Input Program (TDIP) was also used to collect volume data that could be compared to the Autoscope data. Overall, Autoscope data were collected using 51 video detectors over 13 freeway lanes. Note that since the use of TDIP results in some level of human data entry error, it is more correct to state the difference between the Autoscope data and the TDIP data as a percent difference and not a true percent error.

Results

1. In 8 of the 13 lanes studied, there was an excellent correspondence between the Autoscope data and the TDIP data. When optimal detector locations were selected, mean differences varied from 1 to 9 percent. In each of these cases, video detectors were placed horizontally, perpendicular to the direction of traffic flow, with traffic moving away from the camera.

2. In 2 of the lanes studied, traffic was moving toward the camera and results were mixed, even when horizontal video detectors were used.

3. In the remaining 3 lanes, results were inconsistent or poor. The main factors affecting the performance for these cases were the presence of darkness, inadequate camera placement, and the use of vertical video detectors.

Analysis and Recommendations

1. In most of the cases studied, the correspondence between the Autoscope and TDIP data was very good.

2. The horizontal detector orientation proved superior to the vertical detector orientation.

3. The research team has gained significant experience in the optimal layout of the lane detectors,

as well as the sensitivity and persistence settings for the detectors. In addition, the errors induced by vehicle shadows from adjacent lanes have been reduced using the shadow detection algorithm recently introduced into the Autoscope control software. Further experience with the system, and the subtleties of the detector settings, should improve the results gained in future Autoscope applications.

8. RECOMMENDATIONS/CONCLUSIONS

The results from this project indicate that it is possible to measure truck height, length, width, and volumes of freeways by using the Autoscope. But the future work for measuring these parameters by using Autoscope can be improved by considering the parameters of camera alignment, site geometry, and future improvements in the Autoscope system for each case (truck height, length, etc), if applicable. The effect of these parameters for each case is discussed below.

8.1 Truck Height Measurements

Camera Alignment: It is very important to have a proper camera alignment for data collection. For the truck height measurement the camera position should slightly be further away from the truck lane. The distance used in this study was acceptable, but for large trucks (large heights) this distance may not be enough. This goal can also be achieved by using a wide angle lens.

Site Geometry: Since it is not efficient to place detectors against the sky, another requirement is that of a fixed background against which the detectors can be placed. The limited width of the signal post against which the detectors were placed in this study limited the detector spacing to 1 foot only. By having a vertical wooden plank adjacent to the signal post, at least for the top portion, might solve this problem. By this method, the detectors can be placed at a spacing less than 1 foot i.e., 0.5 or 0.25 feet which will tremendously improve the height estimates.

Autoscope System Improvements: Finally, improvements in the Autoscope system in terms of sensitivity for detecting light colors will improve its performance for accurately assessing the heights of trucks with light colors (particularly white), which accounted for most of the wrong measurements in this project.

8.2 Truck Length Measurements

Camera Alignment: Two methods were used for estimating truck lengths: (1) truck progression method and (2) truck speed method. Results obtained by both the methods were not correct and had significant percent errors. Of the two, the main problem with the truck progression method is mainly due to the camera alignment. In this case the camera was inclined at approximately 45 degrees to the direction of truck movement. This gave rise to site geometry problems which were not resolvable. By having the camera inclined straight on to the side of the truck i.e., perpendicular to the truck lane, the truck progression method should give good results. Another condition to be satisfied is that, the camera should be placed at a sufficient distance from the truck lane so that the largest truck is within the field of camera's view. This can be achieved by using a wide angle lens.

Site Geometry: The requirements for the truck height case applies here also. The available background for detector placement should not be obstructed by passing vehicles in the other lanes which will result in unnecessary activation of detectors.

Autoscope System Improvements: The truck speed method for length measurement will give good results with improvements in Autoscope's speed measuring capabilities. The increased sensitivity will improve the efficiency of both the length measurement methods.

8.3 Truck Width Measurements

Camera Alignment: The truck width data were collected with the camera was mounted on the Clark Mast positioned at a distance of 7 feet from the truck lane. It gave a near top view of the site, but some trucks with large heights were not covered completely; that is, they were out of the camera's field of view. The ideal camera alignment for measuring truck width will be when the camera is placed exactly in the center and above the truck lane such that the largest truck width is within the camera's field of view. In this study, this could be achieved by placing the camera on the signal which is above and across the truck lane. Although a wide angle lens was used, a more powerful i.e., a lens which covers a wider area is necessary for increased accuracy and better results.

Site Geometry: Not applicable for this case.

Autoscope System Improvements: Improvements in detector sensitivity will significantly improve the width estimations by using Autoscope. Also the closer spacing of detectors will increase the accuracy of measurements. In fact the closer spacing of detectors i.e., 0.5 ft or less will increase the accuracy of measurement of all truck parameters.

8.4 FREEWAY VOLUME MEASUREMENTS

Camera Alignment: For all the freeway scenes observed the camera alignment was good. A more steeper angle with a wide angle lens will be perfect to eliminate the effect of occlusion and to give excellent results.

Site Geometry: There is no need for any change in the site geometry for any of the scenes.

Autoscope System Improvements: Improvement in detector sensitivity might slightly increase the accuracy of flow rate measurement. The effect of vehicle color can be eliminated with increased detector sensitivity.

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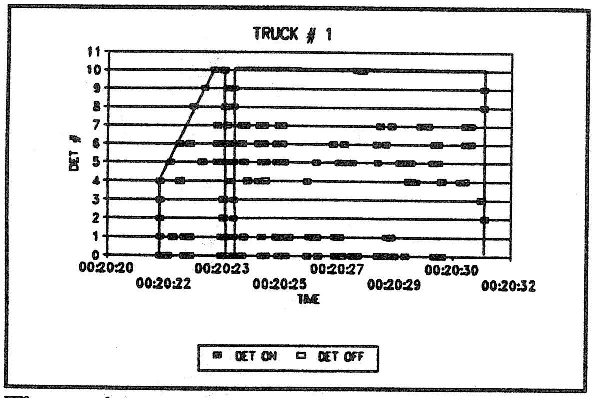


Figure 1

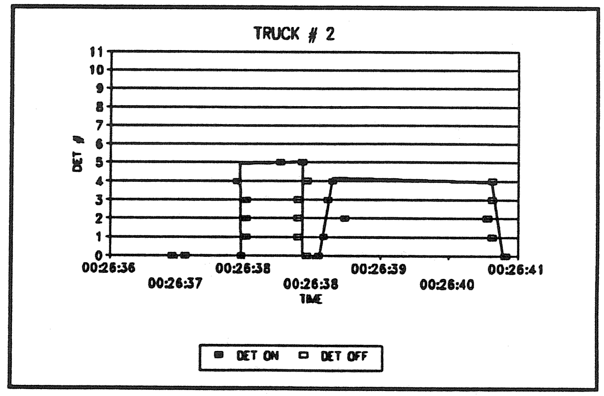


Figure 2

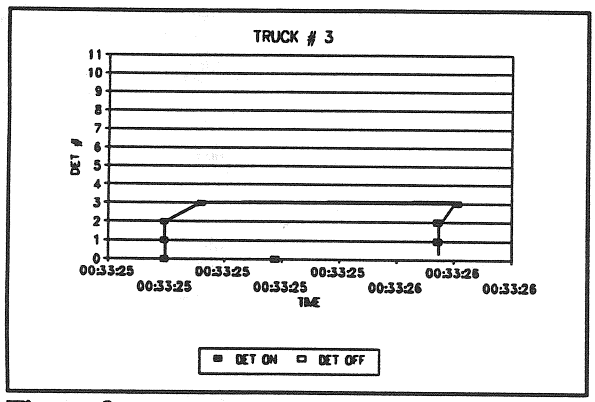


Figure 3

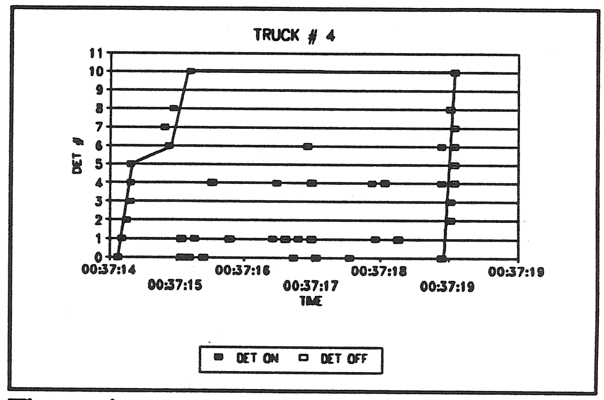


Figure 4

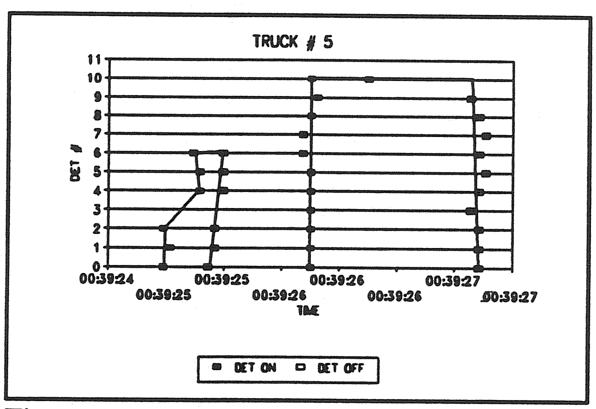
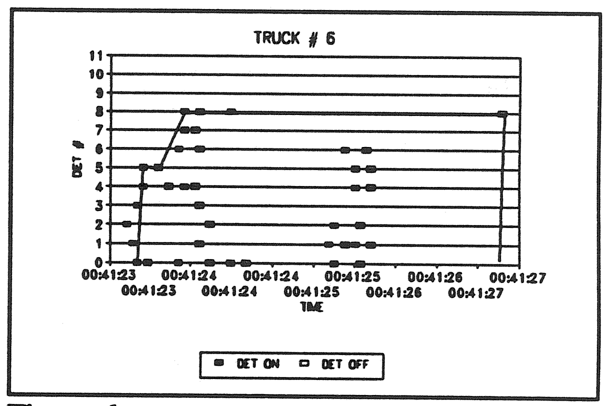


Figure 5



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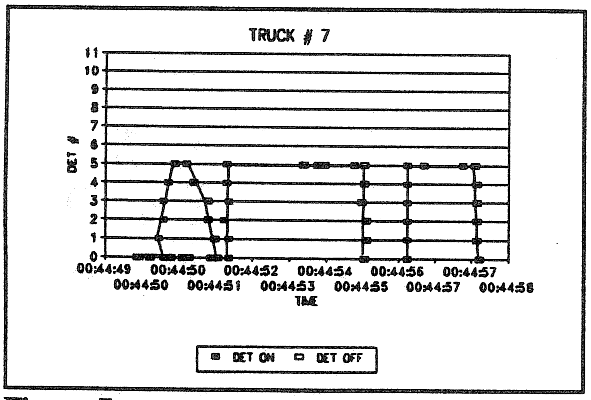

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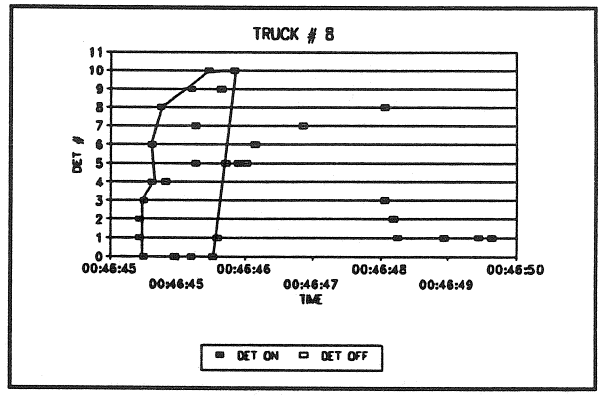

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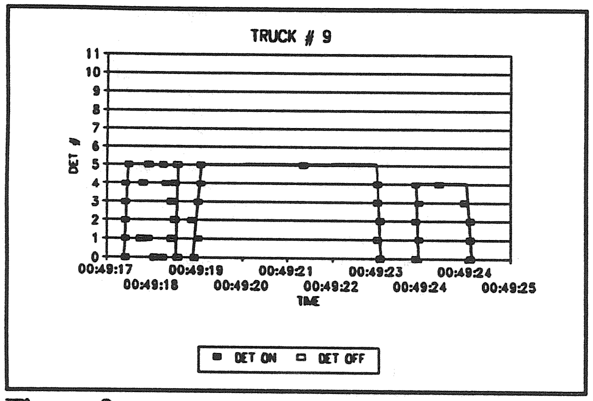

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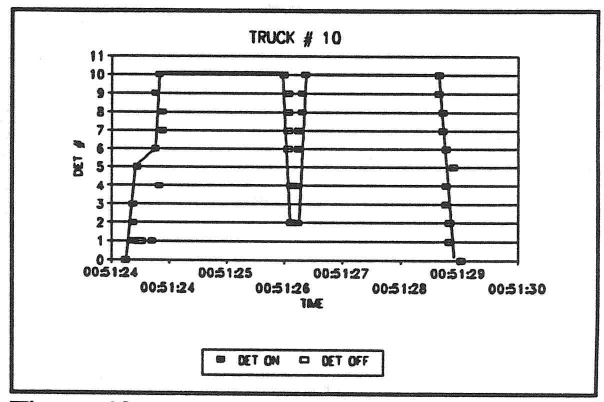

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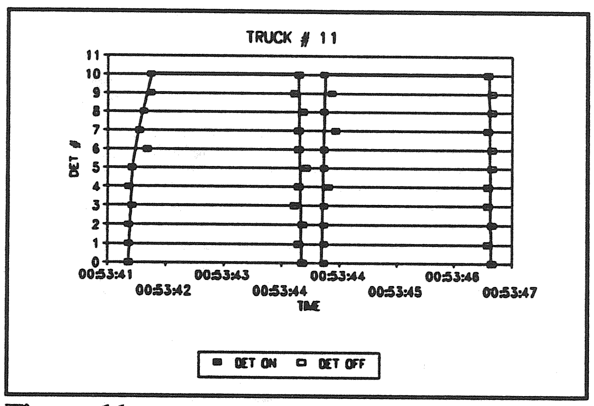

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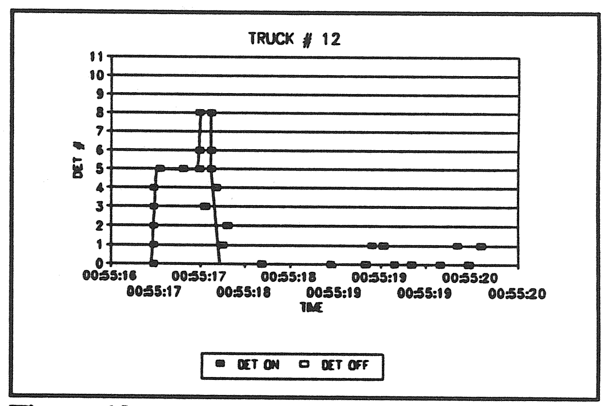

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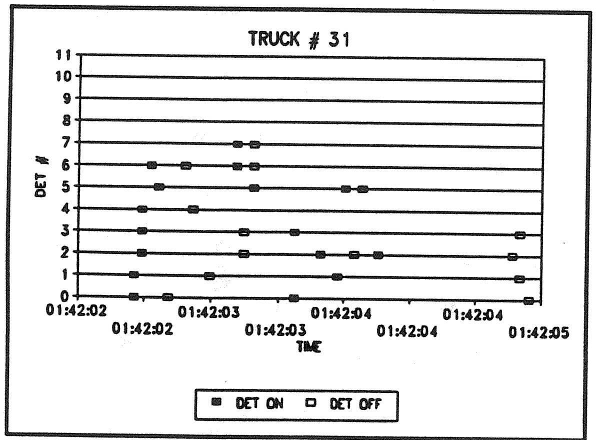

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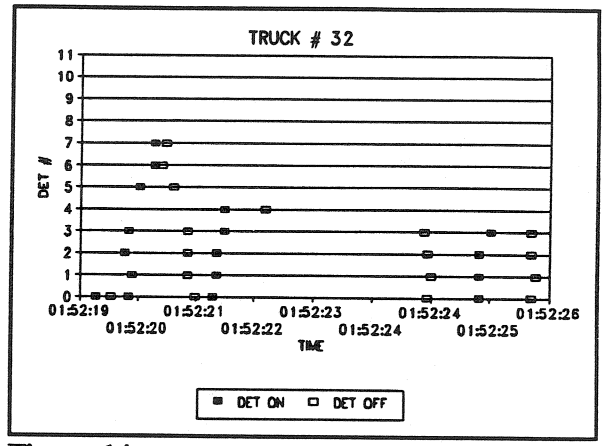

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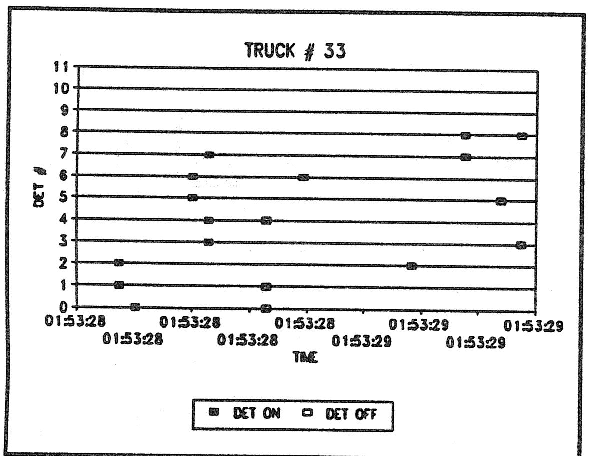

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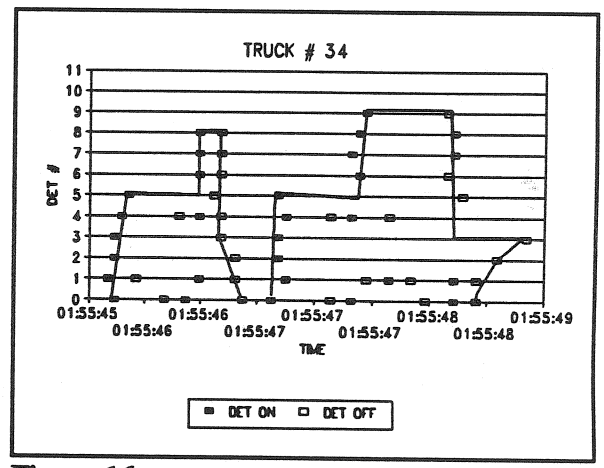

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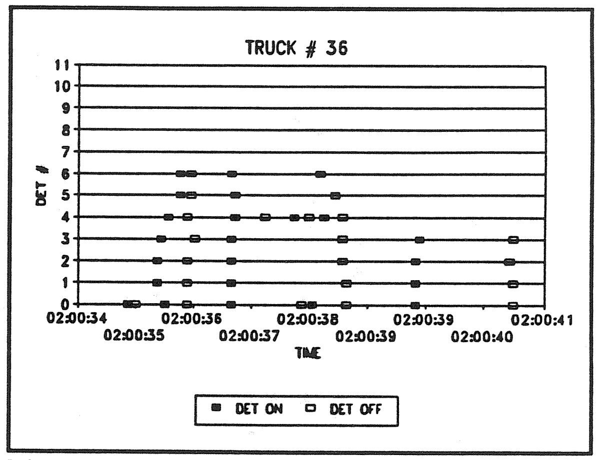

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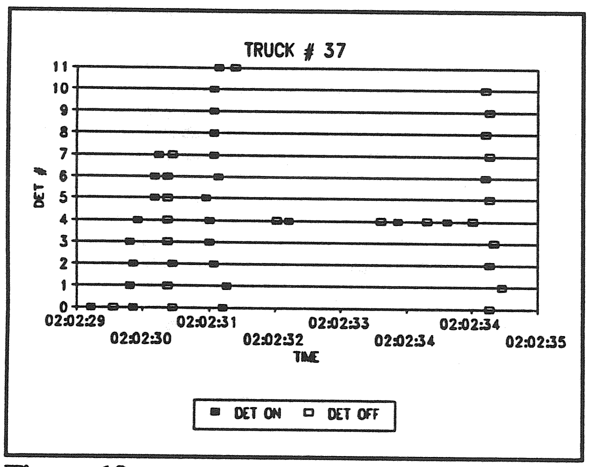

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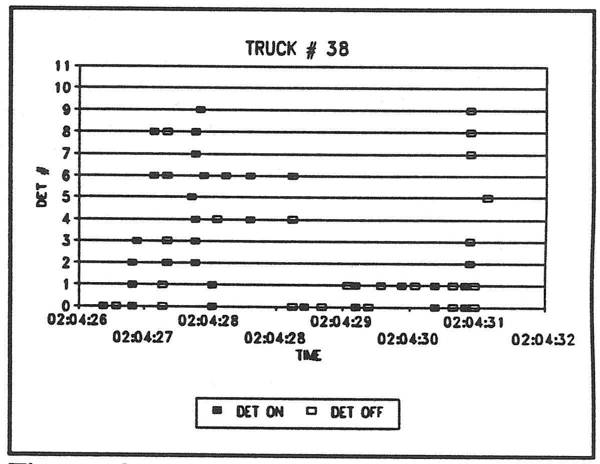

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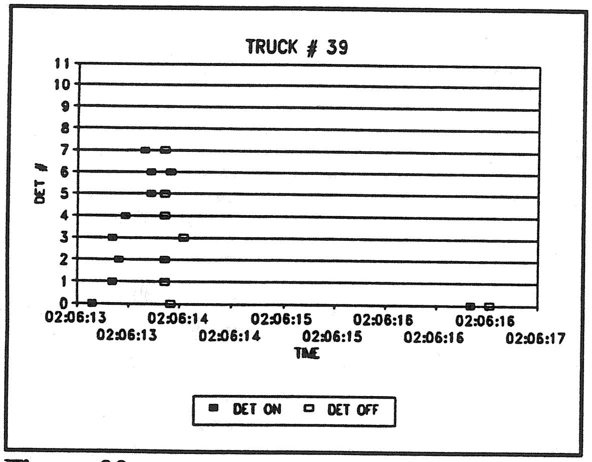

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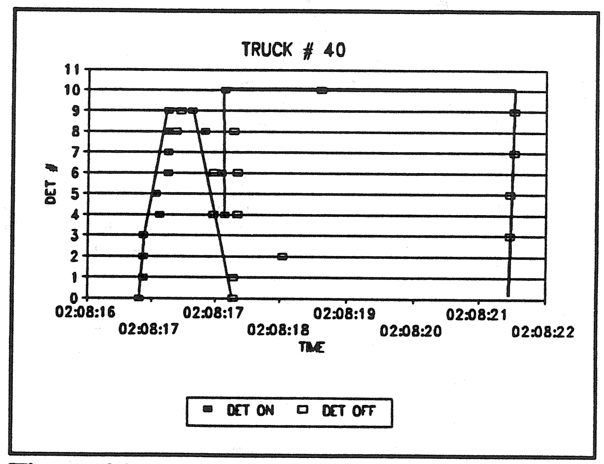

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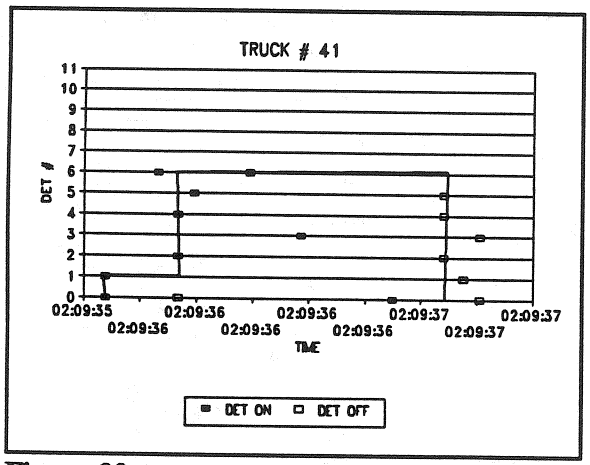

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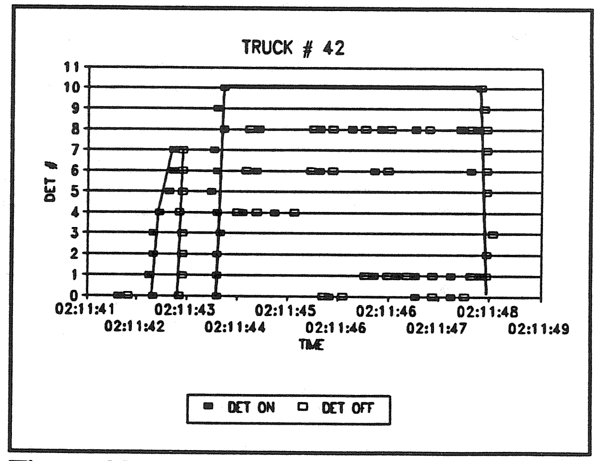

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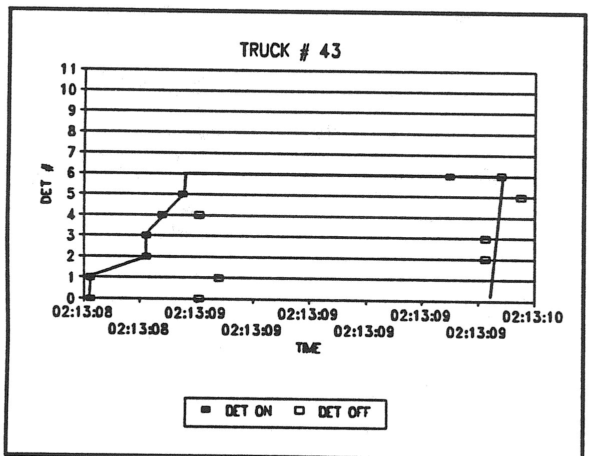

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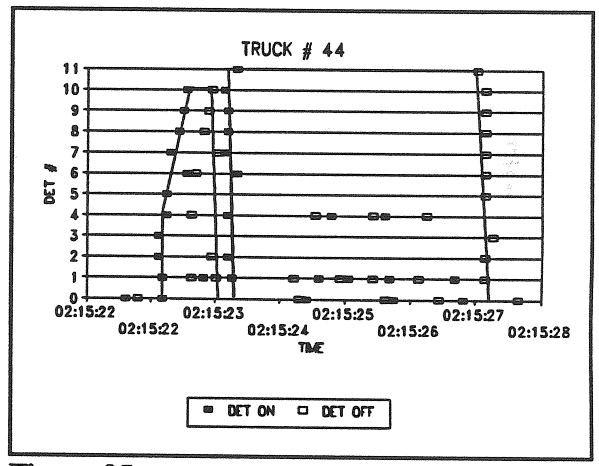

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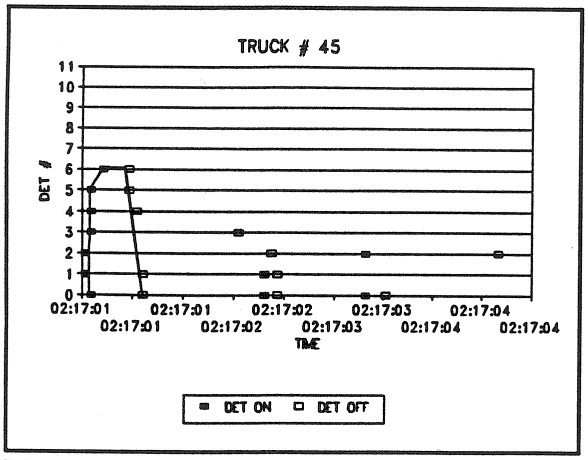

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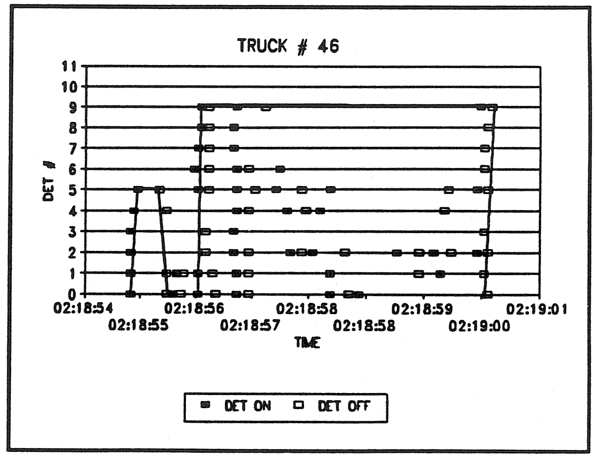

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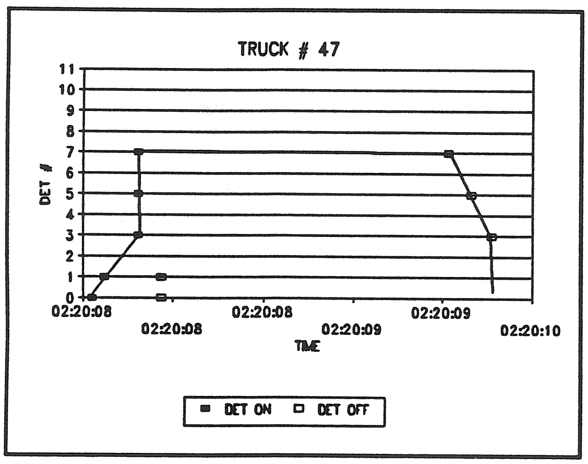

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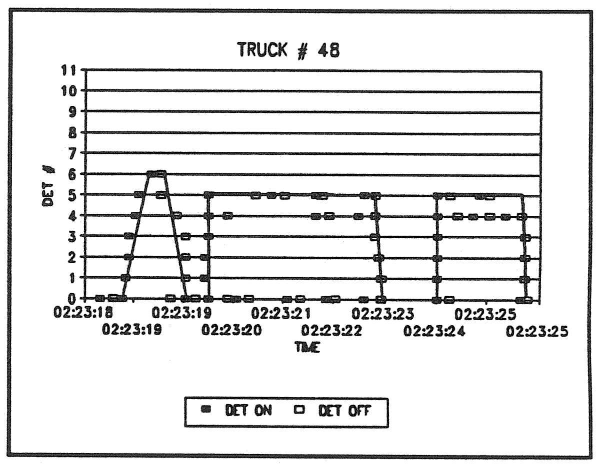

Figure 29